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# Psychological Monographs

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Studies from the Psychological Laboratory of the University of Chicago

# The Diagnosis of Mental Imagery

By

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PSYCHOLOGICAL REVIEW COMPANY

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# ACKNOWLEDGMENTS.

The obligations incurred in the course of the present experimentation are too numerous to be recognized adequately in any brief comment. However, we cannot fail to note our fundamental indebtedness to Professor James R. Angell, both for the original stimulation of our interest in problems of imagery and for constant assistance, suggestions and criticisms throughout the investigation and during the preparation of the manuscript for publication. We also gladly express our gratitude to the subjects who served through the long and often tedious series of experiments. To many of these we are further indebted for helpful suggestions with regard to methods of diagnosis and interpretation of results.

# I. INTRODUCTION.

The problem with which this investigation started was that of determining whether and to what extent forms of imagery which are deficient or lacking in a given individual may be improved by training. While this remained throughout the objective of our inquiry, the actual emphasis of the present work has fallen on another, and a preliminary, phase of the question: *i. e.,* the diagnosis of the individuals concerned with reference to their imagery. From this point of view our study has undergone the same type of change as that reported by Segal in his recent study of imagery. (96, p. 124-125.) He planned to investigate the reactions of individuals of different ideational types to works of art, but found the determination of the types of his subjects so extensive an undertaking that he was unable to carry out his original plan.

We had hoped to find in the mass of literature dealing with imagery a sufficiently comprehensive and accurate series of tests, so that the establishment of the types of the subjects would be a relatively simple matter. On turning to this literature, however, we found too much disagreement as to the significance of particular methods, as well as too much *a priori* reasoning interwoven with experimental facts, to justify an uncritical dependence upon the present quota of tests. Our own early attempts at diagnosis also presented ambiguities of interpretation and revealed complexities in the situation, as a whole, which demanded consideration on their own account. Thus, the preliminary aspects of the problem shifted temporarily to the center of the field.

As a result of the expansion of the preliminary problems, the final problem—that of the susceptibility of imagery forms to training—was crowded into the background. Publication with reference to this phase of the inquiry is, therefore, deferred, awaiting the accumulation of further data.

The preliminary problem as here considered assumed three main forms: (1) The diagnosis of the reagents in question was recognized as the first essential. Accordingly we searched for as correct a statement as possible of the characteristics and behavior of their mental imagery. (2) This attempt stimulated an interest in the *technical* side of the undertaking: *i. e.,* the devising and evaluation of tests for the determination of imagery of the various sensory fields. (3) Finally, these two lines of inquiry led to a more general consideration of the *nature* and *extent* of *individual differences* in imagery and the meaning of imagery *"types."*

# II. HISTORICAL BACKGROUND OF PRESENT DISCUSSION.

The literature dealing with problems of imagery has grown so voluminous that it would be impossible to present a summary of it here. Moreover, there have appeared a number of excellent historical and critical discussions of this literature, which make the necessity for a comprehensive review relatively slight.[1] Especially is this true of the papers by Angell (5), Colvin (29) and Segal (96), which have been published either during the course of our investigation or after its completion They treat in such detail of the methods in use for the determination of imagery types that much of our discussion, as orginally planned, becomes superfluous. Accordingly we have reduced our account greatly, referring only to the most important lines of development.

For more thorough orientation with regard to the status of the work on methods the reader is referred to other discussions, with the following suggestions and qualifications concerning their use: He may profitably first consult Titchener (108) [2] for a concise statement of tests, with directions for procedure. It must be remembered, however, that much work has been done along this line in the period since the preparation of Titchener's manual, although relatively few new tests have been proposed. These investigations have made necessary a more critical attitude with regard to certain of the tests (*e. g.*, Kraepelin's test, memory tests with distractions and with reversals, etc.) than that assumed by Titchener, who gives the impression that most of the tests described are adequate. The first systematic attempt to evaluate this group of tests was made by Bell and Muckenhoupt (13), who undertook an estimation of the consistency of the data gained by these methods from four subjects. They felt justified in asserting that the methods proved reasonably consistent, though Colvin (29) maintains that this consistency was not so great as standard tests demand.

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[1] Note especially Angell (5), Colvin (29), James (53), Lay (66, pp. 47-53), Segal (96, pp. 126-132), Titchener (108, Instr. Man.).

[2] The discussion of methods in Myers' experimental text (80) is too inadequate and uncritical to demand serious consideration.

Of a more thoroughly critical character than the above are the discussions of methods by Colvin (29) and by Angell (5), with whose criticisms the present writer is for the most part thoroughly in accord. Minor variations from the usage of each of these will be noted as they appear. We would call attention especially to Colvin's criteria of "adequate tests for ideational types" (p. 237). The first of these seems to us of fundamental importance; *i. e.,* "the test determined upon for any particular type should prove itself when employed with an observer known to be clearly of that type." Aside from any question of the ultimate subjective or objective use of any test it should first be justified when checked up by the introspective reports of competent observers. The second criterion—"that the various tests should be in agreement with each other"—is more open to question in the light of recent investigations. These show so strong a tendency on the part of many individuals to use different combinations of images when conditions are even slightly changed, that consistency among tests should hardly be expected. In diagnosing such cases it is important to use tests which expose these variations, if we are to have an accurate survey of the range and distribution of the subject's imagery. But we should then lack consistency among the tests.

Our only point of divergence from Angell's account appears with reference to the classification of tests as subjective or objective and will be discussed in that connection.

In our survey of the literature we have been concerned with the nature of the division into imagery "types" as well as with the methods employed for their determination. These are but two sides of one problem, since the recognition of individual differences in the nature and use of imagery furnishes the motivation for the search after adequate tests, while the data thus obtained may materially modify the view of types. In fact, this is a form of interaction which has taken place historically. The pioneer work of Fechner, Galton, Charcot and others called attention to striking differences between individuals in the nature and abundance of particular forms of imagery, while later work attempted to put more content into these distinctions by the employment of more delicate diagnostic methods. We shall first consider the latter problem—the development of methods for investigating imagery—since the doctrine of types has been largely modified by results which appeared in the course of this development.

## A. METHODS OF INVESTIGATION OF INDIVIDUAL DIFFERENCES IN IMAGERY.

In the following brief statement we attempt to indicate the methods now in use for the determination of individual differences in imagery, with special reference to instances of their application which may serve as evidences for or against such use. Tests have not been described or criticised in detail, when descriptions and criticisms by other writers are available.

*Introspective Analyses by Competent Observers.* This was one of the first methods used, and is still contributing detailed information relative to individual peculiarities. For typical instances of its use see Baldwin (9), Colvin (31), Dodge (36), Egger (39), Fechner (40), James (53), Wilfrid Lay (66), Stricker (103 and 104), Titchener (109). The chief objection to dependence upon this method is the fact that its contributions are haphazard and accidental, rather than controlled.

*The Questionary.* This is practically an outgrowth of the preceding method, involving the attempt to secure more systematic information: (1) by the use of a carefully selected list of questions, and (2) by presenting the same questions to a large number of different observers, often quite untrained in introspection. Since Galton's introduction of the questionary into psychological experimentation (46 and 47) it has been used extensively, though usually with sets of questions different from those which he employed. For various forms of questionaries and reports on results gained thereby, see the following: Armstrong (6), Beaunis and Binet (12), Betts (15), Fränkl (43, sec. 58), French (45), Wilfrid Lay (66), Seashore (94), Stetson (101), Titchener (108, Stud. Man., p. 200). The method has been severely criticised from the very time of its presentation by Galton. Note, for example, Bain (8), Colvin (29, p. 226), Angell (5, p. 68), Titchener (108, Instr. Man., p. 387-390). Yet in spite of criticisms data obtained by the questionary form the basis of many of the current views with regard to imagery, such as the traditional theory that women are better visualizers than men.

*Word Methods.* A group of methods has been comprehended under this name by Titchener, who describes them in detail (108, Instr. Man., p. 394-395). They all take as their criterion of imagery some phase of the various possible reactions to words. Most of them are association tests in principle. They have not been directed primarily toward the analysis of verbal imagery, but have been concerned rather with the illustrative imagery implied in the content of the word. *Kraepelin's test* (58), in which the subject is called upon to construct one list of objects characterized by colors, and another of those characterized by sounds, which lists are considered indices of his imagery, has been well criticised by Colvin (29, p. 226-227) and by Angell (5, p. 66).

*Secor's test* (95) is an association test in which the words have been selected with special reference to their capacity for stimulating various forms of imagery. See Angell (5, p. 68) and Colvin (29, p. 227). As used by Secor, and more recently by Segal (96), careful introspective comments constitute an essential part of the procedure. This type of test has also been used without such introspection, as in W. A. Lay's tests with children (64), in which application the criticisms urged by Angell and by Colvin against Kraepelin's test seem pertinent.

Various forms of the "*Method of Style,*" used first by Fraser (44) and Wilfrid Lay (66), and given this name by Titchener (109, Instr. Man., p. 401), belong properly with the word methods, since they involve inference of the imagery employed from the words used in literary productions. Colvin, while criticising this form of test (29, p. 232), uses a similar method in the investigation by himself and Myers of children's imagery (32). They devised a story, "constructed with the purpose of appealing in its various parts to the three chief types of mental imagery (visual, auditory, motor)." Since an equal number of words was used (supposedly), representative of each field, any preponderance of one variety in the subject's repetition of the story was considered significant of a corresponding emphasis on that field of imagery; a method which appears to be open to all the criticisms which have been made against the method of style.

Another method which makes use of word contents for purposes of analysis is employed by Netschajeff (81), Lobsien (68) and Pfeiffer (84), all working with children. They tested the memory capacity for different kinds of materials, including words referring to visual objects, sounds, touch, temperature, movement, etc., as well as sounds and visually presented objects themselves. From a comparison of the relative numbers of words of each group retained they inferred the imagery type. Colvin tried a similar experiment, but expresses himself now as believing that "they are far from being an adequate test for the ideational type of the subject" (29, p. 232).

*Memory Tests.* Of all the imagery tests proposed since the questionary the most frequently suggested and most extensively used are the various methods which demand the arousal of *memory images.* Comparison of the relative strength or importance of these images is attempted on the basis of either objective results or introspective comments. The following variations of memory methods are among the most important devices attempted for securing available results for this use.

(1) *Presentation Through Various Sensory Fields.* Letters, words, nonsense syllables, etc., have been presented to the eye, to the ear and to either or both with the accompaniment of articulatory or writing movements. The accuracy of the work has been considered an index of imagery type, the assumption being that an individual learns most successfully by way of the sensory field which corresponds to his most favored form of imagery. Jastrow

(54), Meumann (75), Fränkl (43), Myers (80), Quantz (88) and others have used it and given it their support.[3] Radossawljewitsch (89), Segal (96) and Sybel (106) have applied the test more critically with negative results. The two latter present evidence showing conclusively that the method is not of value *for determining imagery* unless checked up by introspection. See also Angell (5, p. 63).

(2) *Use of Different Kinds of Materials.* This is practically a variant of the above test, though it may or may not involve a difference in the character of the presentation. Comparison may be made of memory for colors, forms, sounds, movements, etc., or of memory of names referring to such materials. (See word method described above, p. 7) Angell's criticism of the preceding test, that the possibility of translation from one sensory field to another invalidates the inference, applies to this test also. Such translation is shown elaborately and convincingly in the experiments of Fracker (42) and of Kuhlmann (62) with sounds, and those of Gamble (48) with smells. Each particular test must, therefore, be justified experimentally by comparison of quantitative results with introspection before it can be used with any prospect of success without introspection.

(3) *Emphasis on Arrangement of Material.* Another group of memory methods is characterized by emphasis upon the order and arrangement of materials. Two main forms of this appear: one demanding the retention, without modification, of a well-defined visual arrangement; the other calling for retention of the arrangement but reproduction in a changed order. *Binet's letter squares* (21) are the most common forms of the first method. For full description of these see Titchener (109, Instr. Man., p. 396), Colvin (29, p. 227) and Angell (5, p. 69). Binet mentions the test briefly, suggesting that errors in location indicate defective

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[3] It is possible that the terms "eye-mindedness" and "ear-mindedness" as used by Jastrow and others should not be interpreted as referring exclusively or even primarily to differences in *imagery* type. In that case the use of this test is more justifiable, since it may indicate the sensory field by which the subject learns best. The other interpretation has usually been made, however, by later writers.

visual imagery. This form of test has been used frequently, simply as a convenient way of presenting visual materials, without reference to the factor of arrangement. Such seems to be its most legitimate use, since it has been found that retention of arrangement may be as successfully accomplished on the basis of auditory sequence as by means of a visual image. For more extensive criticism see Angell, *loc. cit.* Colvin and Myers (32) present three interesting devices, which are practically modifications of this method, but they offer no evidence, other than theoretical, in support of their objective use, since the work was done with children exclusively.

The second way in which the factor of arrangement has been used consists in requiring a reproduction of the members of a series in an order different from that in which they were given, the assumption being that one who visualizes the terms will find this change easier than one who relies on auditory imagery. Binet (17) first used the method for testing the two phenomenal calculators—Diamandi and Inaudi—with series of twenty-five letters which had been *learned* for normal reproduction. The method is usually proposed with confidence on the strength of his results,[4] though Binet's own account contains highly conservative statements. He holds that not only the *type* of memory is being tested but also the *force,* and concludes: *"Le témoignage du sujet malgré son caractère subjectif, doit toujours être pris en considération."* His experimental results also suggest caution. While he found that Diamandi, the more visual of the two, had better records for the changed order than did Inaudi he points out that even Diamandi was far less rapid for the changed than for the normal order. In the second place, Diamandi's learning time was three minutes, whereas Inaudi's was only forty-five seconds: a significant fact, since it may indicate that Diamandi learned the series more thoroughly than did Inaudi, and, therefore, had it under more perfect control. In the third place, a comparison of the rates for normal reproduction shows that even here Diamandi was the more rapid, his time being nine seconds to Inaudi's nineteen. Whatever may be the cause of this difference, it casts doubt upon the significance of a similar superiority in time shown by Diamandi in the changed reproductions.

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[4] Titchener says (108, Instr. Man., p. 401): "Let O learn a square of twenty-five figures or letters. If he is visual, he can repeat the figures in any order—by diagonals, spiral-fashion, etc., almost as easily as he can repeat them line by line; if he is auditory or auditory-motor, he will stumble and hesitate when called upon to travel out of the order of learning."

See also Colvin (29, p. 234).

It seems clear that further experimental support must be produced before we are justified in assuming any less conservative an attitude toward the objective results than does Binet. Meumann (75) and others suggest the method, but do not present experimental results.

(4) *Methods of Disturbance or Distraction and of Helps.* An extensive group of methods has been developed under these heads, especially by the German investigators. Cohn (28) was apparently the originator of the method as a test for imagery, though Meumann (75) has given the most complete formulation of the devices which may be used. For criticism of the method as a whole the reader is referred to Angell (5, p. 63-66) and Colvin (29, 229-231).

The underlying principle of the "distraction tests" is the assumption that a sensory activity or an imagery process of any sort interferes with the simultaneous arousal of imagery of the same kind. Thus, sounds conflict with auditory imagery, sights with visual, movements with motor, etc. Any diminution in efficiency under conditions of distraction is taken as evidence, therefore, that the given disturbance is allied to a favored form of imagery. The extent of the interference is considered a measure of the dominance of this imagery.

The methods of helps are less unified in principle, agreeing simply in the assumption that there are certain devices which are helpful to individuals of one type and not to others.

These methods have been used extensively with children [see Meumann (75), Fränkl (43), Pfeiffer (84), etc.], but as the assumption is made in such cases that the tests are adequate to determine type, we receive no aid from these sources for their evaluation as methods. The same thing may be said of the use made of them with adults by Jastrow (54) and Quantz (88).

Three investigators [5]—Cohn (28), Segal (96) and Sybel (106)—have tested them by reference to introspective data. Cohn found evidence in support of the distraction principle in its use as a test for imagery, though the slight quantitative differences between individuals classed by him as visual and others classed as mixed indicate a large probability of error in diagnoses based entirely on an arbitrary quantitative standard. Neither Segal nor Sybel found a thorough confirmation of Cohn's principle. Segal contends that, while the quantitative results would lead at times to a correct judgment, at other times they lead far astray. Sybel also found certain marked deviations from the behavior which the upholders of the distraction methods would have us anticipate.

(5) *Direction by Experimenter with Regard to Imagery to be Used.* Titchener (108, Instr. Man., p. 398) presents this modification of memory tests, indicating that it has been found satisfactory in his laboratory. The subject is requested to learn the material, now by visual imagery, now by auditory, now by motor, etc. The imagery by which he achieves the highest score may be considered his most favored imagery, and his classification is thereby determined. Titchener does not discuss the difficulties incident to this method, foremost among which we should place the uncertainty as to the subject's obedience to the directions. If this is lacking, as it may be in spite of the greatest effort on the part of the subject, the method becomes a failure.

(6) *Observation of Errors, Peculiarities of Behavior, etc.* Still another adaptation of memory tests for the determination of imagery is the observation of various side-products, which may appear in connection with any of the preceding methods. One of these, suggested by Binet (21) and used by many others, is the consideration of the character of the errors as indicative of visual or of auditory confusion. Confusion of like-sounding letters—*e. g.,* b and v, f and s—would indicate dependence upon auditory or motor imagery rather than upon visual, while confusion of like-

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[5] Miss Downey's contributions (37) with regard to the distractions are not referred to here, because they were not concerned primarily with the value of these as diagnostic methods. They will be discussed in connection with the account of our own results. See p. 113 ff.

appearing—*e. g.*, e and o, v and w—implies prominence of visual imagery. These are generally admitted to be desirable indications where such errors do appear. But it is obviously a method difficult of control, since the subject may fail to make any significant mistakes. He may simply omit terms, or substitute others which do not resemble the correct ones either in sound or in appearance, or which resemble them in both respects—*e. g.*, m and n, b and p. Miss Sharp (97) notes these difficulties as appearing in her attempt to make use of this criterion. See also Angell (5, p. 70.)

Segal (96) mentions other secondary criteria under the head of *"äussere Verhalten."* He claims that the visualizer is apt to close his eyes while thinking, to be slower in giving the reproduction, to retain letters longer than other subjects, to reproduce without regard to order, etc. Meumann (74) gives a similar description, but G. E. Müller (78, p. 17-18) contests almost every point on the basis of his own results.

*Observation of Imagery Used in Connection With Other Problems.*[6] In addition to the tests explicitly designed to investigate imagery there is a steadily increasing number of studies contributing valuable information with regard to imagery, which they investigate as a phase of some other problem. In the field of mathematics there is Browne's "Psychology of the Simple Arithmetical Processes" (24), with its careful analysis of the imagery employed in these mathematical computations; also Thorndike's "Effect of Practice in the Case of a Purely Intellectual Function" (107). Among the investigations of memory from this point of view are Kuhlmann's studies of the memory for visual and for auditory materials (59, 62), Miss Gamble's experiments in the memorizing of colors, smells and nonsense syllables (48), G. E. Müller's recent extensive study (78), etc. In the field of voluntary action important contributions are made by Miss Downey's study of the imagery controls for handwriting (37), and Book's monograph on the acquiring of skill in typewriting (22). Evidence thus acquired accumulates slowly, but has many advantages when gained. Chief among these is the fact that it represents variations in the actual *use* of imagery in concrete situations.

[6] Of this general character are the tests described by Angell (5, pp. 72-80).

## B. CLASSIFICATION OF TESTS AS SUBJECTIVE, OBJECTIVE OR BOTH.

We have referred during this discussion to the character of tests as objective or subjective. This demands, perhaps, a word of explanation. By an objective test we mean one which furnishes results, either qualitative or quantitative, which are sufficient to indicate the individual's type without reference to his introspection. This does not mean that such tests may not have acquired this validity by the use of introspective data originally, but simply that it is not necessary to call for introspection at present. The demand for such tests obviously arises from a recognition of the difficulty of introspection and the desire to study the imagery of persons unskilled in introspection, especially children. In general there are three classes into which imagery tests naturally fall: (1) The purely *subjective*, relying exclusively on the subject's introspection; (2) the purely *objective*, as described above, and (3) the combination of *subjective and objective*, where the objective results are used as a check on the introspection, and vice versâ. The tests which we have described may be classified according to the use which has been made of them, as follows:[7]

1. *Subjective.*
   - a. Individual introspective records—uncontrolled.
   - b. Questionary methods.
   - c. Introspection on imagery used in connection with other experiments.
   - d. Projection method used by Miss Martin.[8]

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[7] Our grouping of tests under these heads differs slightly from that of Angell (5), although the definition of the terms is essentially the same. The difference in classification arises from the fact that no purely subjective group is recognized in a practical way in his classification, the tests which we have classed as subjective being brought under the subjective-objective group. This usage does not seem to us justified, since certain tests, notably the questionary, appear entirely subjective in their contributions according to the terms of the definition.

[8] This method has not been described in the preceding survey of tests because no account of it had appeared when this material was formulated. For a brief statement of the method see Martin (70).

2. *Objective.*
    a. Memory tests—as used by Meumann, Pfeiffer, Fränkl, Colvin, etc.
        1. With different modes of presentation—visual, auditory, etc.
        2. With materials appealing to different sensory fields.
        3. With emphasis on order of presentation and reproduction.
            (a) Order unchanged in reproduction.
                (1) Binet's letter squares, as sometimes used, without introspection.
                (2) Colvin's modifications of these.
            (b) Order changed in reproduction. "After" Binet. Spelling backward allied to this.
        4. With distractions or disturbances—as used by Meumann, Fränkl, Colvin, etc.
        5. With helps—as used by Meumann, Fränkl, etc.
        6. Observation of significant errors with any of above tests. See Binet, Cohn, Meumann, Fränkl, etc.
    b. Word tests. Conclusions drawn from contents of words used.
        1. Kraepelin's test—as usually applied
        2. Association tests—as used by W. A. Lay, etc.
        3. Method of style—as used by Fraser, Wilfrid Lay, Colvin.
3. *Combination of Subjective and Objective.*
    a. Memory tests—as used by Binet, Cohn, Segal, Sybel, Schumann, etc. Methods identical with those given under 2—a, except for importance given to introspection.
    b. Association tests with introspections—as used by Secor and Segal.

With reference to the relative merits of the three types of procedure indicated above, psychologists fall into as many groups.

1. A large number of investigators express their approval of objective tests by their own reliance upon them. (See Meumann,

W. A. Lay, Fränkl, Pfeiffer, Netschajeff, Lobsien and others.) Some of these, it is true, have also called for introspection, but usually not with reference to the problems from which the quantitative results were obtained. For example, in Netschajeff's questionary used also by Fränkl, such questions as the following appear: "Which is easier: to prepare a lesson silently or aloud?" "What study is the hardest for you and which the easiest?" etc. It is considered an indication of the auditory-motor type if the subject learns most readily by studying aloud, if his favorite studies are modern languages, history and music, etc. The interpretation of these introspective reports is evidently as arbitrary as that of the more strictly objective material.

2. At the other extreme are those who are convinced that no tests have been justified by their fruits as objective, and who believe that the obstacles in their way are insuperable. The sole reliance must be on introspection, they claim. Many take this attitude by implication: *i. e.,* by the exclusive use of subjective tests. Betts (15) frankly takes this stand, attempting to compensate for whatever the introspective data may lack in accuracy by the amount of such material, and the exact statistical treatment thereof.

3. On the middle ground between the two extremes are those investigators who believe that assistance may be gained from both sources—introspection and objective results: that at best the data for diagnosis are inadequate and that no help should be discarded. They consider the objective results valuable for confirming or casting doubt upon the introspection. Again, many writers tacitly stand sponsor for this view. Segal (96) and Angell (5) openly adopt it.

The confusion and contradiction here indicated are characteristic of the present condition of the literature on imagery. The need of further standardizing is evident. With reference to the so-called objective tests more careful establishment of technique and a more convincing assemblage of evidence in their favor are clearly necessary before they can be admitted into the realm of accepted psychological tests.

### C. DEVELOPMENT OF THE CONCEPT OF "IMAGERY TYPES."

Simultaneously with the attempts to work out adequate tests for discovering the kinds of imagery used there appeared efforts to formulate individual differences in this respect more satisfactorily. Though the recognition of images as playing a part in mental processes dates back to Aristotle at least, the doctrines of "imagery types," and even that of marked individual differences, are of much more recent origin. Since the precipitation of this concept by Fechner (40) and its endorsement and elaboration by Charcot (27), Galton (46 and 47) and others, it has undergone numerous modifications. Probably never has its acceptance in extreme form been so enthusiastic and general as in the early period of its history. The truth contained in the proposition that individuals differ widely in their imagery equipment served to explain so many of the problems which had troubled psychologists that it was seized upon with eagerness. It was maintained that every individual belongs in one of three distinct groups—"visual," "auditory" or "motor"—or in a fourth class which combines the characteristics of the other groups—the "mixed type."

The fact that words and other symbols are as susceptible to presentation in the various image forms as are more concrete materials was recognized, especially by the students of aphasia, though the bearing which this might have on the assignment of individuals to types was not appreciated until later.[9] In this connection it is important to note the fruitful controversy which arose between Stricker (104) and Egger (39) with regard to the relative importance of auditory and motor elements in verbal imagery.

From this recognition of the fact that words are capable of presentation in the various image forms it was a natural step to the insistence that specific account should be taken of verbal imagery in any consideration of the type of a given individual. Meumann (75) has pointed out that the predominant form of imagery used for words is, as a rule, different from that for non-verbal materials: that, in the former case, auditory-motor images are more prevalent, while, in the latter, visual more frequently predominate. The most common type, therefore, involves a combination of visual images for objects, and auditory-motor for words, though many variations appear in this general scheme. At any rate, it is always important, in his opinion, when speaking of an individual's type, to indicate whether reference is made to object imagery, to word imagery, or to both.[10]

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[9] For special discussions of verbal imagery see the following: Aubert (7), Baldwin (9), Ballet (10), Dodge (36), Egger (39), Keraval (56), Pick (87), Saint Paul (91), Secor (95), Stricker (104).

Even this division into verbal and non-verbal fields of imagery failed to meet the demands of the situation. There appeared a growing tendency to draw the lines between types less rigidly, for it proved practically impossible to discover individuals belonging to the "pure" types. The statements of this fact, however, are often clothed in vagueness, leaving the reader to draw his own conclusions as to what constitutes a "mixed" type, to which all individuals supposedly belong. Beyond the obvious fact that it implies the use of more than one form of imagery by a given individual, there is ambiguity. It is uncertain, first, whether it is meant that several kinds of imagery are used in combination for one task, or that a change in imagery appears with a change in conditions. A further difficulty with this way of meeting the problem is the fact that it tends to minimize the individual differences which do exist, by forcing all persons into the large group of mixed types.

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[10] The German terminology for this distinction is more satisfactory than the English equivalents. They refer to "Sachvorstellungstypen" and "Wortvorstellungstypen." The term "concrete" has been used quite generally to describe the imagery included under the German "sachlich" or "anschaulich," but is open to obvious objections. The image of a *word* used in a memory series or for spelling is just as concrete as any non-verbal image, though in certain other connections the force of the distinction is clear. The expression "imagery for objects," aside from its awkwardness, is objectionable, because it tends to attract the attention exclusively to visual imagery. "Non-verbal" is most accurate when we wish to include everything but verbal, but is unsatisfactory because of its negative clang. Since we have no single comprehensive term to suggest, which avoids these difficulties, we shall vary our usage with conditions. For example, when we wish to refer to the "sachlich" imagery which represents the content of a word, we shall refer to it as *illustrative* as opposed to *verbal.* When we wish to indicate the difference between learning a series of objects, as in a picture, by visual representation of them and learning them by their names, we shall speak of visual *copy* images or *memory* images as opposed to *verbal.* Under other conditions we shall usually employ either the accepted term "concrete" or the term "non-verbal."

One attempt to meet the latter objection is represented by a partial return to the earlier view of distinct types. Though it is agreed that in the last analysis all persons probably belong to mixed types, in the sense that they operate with more than one image form, it is insisted that there are marked differences in emphasis. The terms "visual," "auditory" and "motor" may, therefore, be retained, if they are understood to signify cases where visual, auditory or motor imagery is predominant.[11] Yet, in spite of the apparent simplicity of this solution, it has brought its own difficulties, among which are the following:

(1) One of the first difficulties to present itself is the uncertainty whether a given image form should be judged predominant because one individual excels others in that respect, or because it is superior to the other forms used by that individual: *i. e.,* in Segal's terms, whether an "inter-individual" or an "intra-individual" criterion should be applied. Reference to the tests as they have been employed reveals considerable variation in usage on this point, with apparently no recognition of the fact that there has been a shift in standards.

(2) To further complicate the problem there is ambiguity as to what constitutes "predominance" of any one form. For example, superiority may be attributed to visual imagery because it is more vivid and intense than the auditory, or because it is more profuse and more readily summoned, or because it is more accurate and reliable, etc. The question may be answered off-

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[11] Segal has termed this view a quantitative division as contrasted with the earlier, primarily qualitative, distinctions. As we understand Segal, this quantitative grouping comes in for as severe a denunciation as the qualitative. His criticism is quite extensive, but the following sentence may be taken as representative: "Schon darauf sieht man, dass die Lehre von den Vorstellungstypen nicht auf die quantitative Verschiedenheit der Vorstellungsmaterialen gestützt werden kann." (96, p. 130.) We therefore dissent from Colvin's interpretation of Segal's view, where he says: "Segal concludes . . . that the qualitative conception of ideational types must be abandoned for a quantitative distinction." (29, p. 225.)

hand by the assertion that that imagery is best which is superior in all these respects, and similarly for the lesser degrees of superiority. But the practical availability of this solution becomes slight, if it is true, as certain writers claim, that these attributes of the imagery equipment are, to some extent at least, independent variables: if, as Seashore holds (94, p. 112), "An image may be very vivid but flitting; it may be complete but faint."

Under these conditions it becomes necessary, either to study a subject's imagery with reference to all these aspects before passing judgment on his type, or to define the meaning of "type" in such a way that a general survey is not demanded. Most writers have neither attempted the former nor explicitly undertaken the latter.

The former solution would involve the evaluation of a subject's imagery from all these points of view in such a way that each attribute would be given due weight in the estimation of the excellence of a given image form. But here another obstacle confronts us. How much frequency of visual imagery will compensate for a lack of detail? How vivid must auditory imagery be to make up for a deficiency in accuracy? We do not find that any investigator has worked out a system of reckoning along these lines. Seashore (94, p. 112) and Angell (5, p. 101-104) both maintain that a study of imagery should include specific consideration of all these factors, but do not discuss their relation to the doctrine of "imagery types."

The most direct way of defining "type" so that a consideration of all these attributes is unnecessary is the arbitrary selection of one of these characteristics, or even a small group, as the determinant of the type. This has been done, sometimes consciously and sometimes with no apparent recognition of the issue. Thus *frequency* is frankly adopted as the basis of type by Feuchtwanger (41). Certain tests, such as Kraepelin's and Secor's, which call for an enumeration of images, practically place the emphasis on this criterion. The questionaries, as ordinarily given, put almost the whole emphasis on *vividness and frequency*. Betts' statistical formulation of the answers to his questionary (15), for example, represents the resultant of these two factors.

On the other hand, the objective methods, especially those which make use of memory processes, put the major emphasis on *accuracy* of imagery. Exclusive use of one or another of these methods may, therefore, commit the investigator to the virtual adoption of one of these standards.

Segal's view (96) also makes the evaluation of these several attributes unnecessary. It is much too complicated for presentation here, but its striking feature is his insistence that neither vividness nor frequency is significant in determination of "Reproduktionstypus."[12] The question is simply what imagery is used when several kinds might be used for the given task; in other words, when the material is reproducible in a two-fold or in a three-fold way. The underlying ground for this assertion is the fact that he identifies the "type," not with the total status of imagery in the given individual, but with the inborn tendency to use one kind of imagery rather than another. Where material can be reproduced in only one way the result may furnish no indication as to which imagery is naturally strongest, since the subject may have to use a weaker form. The same type of consideration serves to explain the shifts in imagery which appear with change in the complex to which materials used in the tests appeal.

Sufficient has doubtless been said to indicate the unstable condition of the doctrine of "imagery types." We shall not undertake at this point a critical comparison of these divergent views. Our own attitude toward the distinction will appear in the discussion of our experimental data. It seems significant of the trend of interest in the imagery problem as a whole that the question of "imagery types" as such has, for the most part, moved into the background, while the search for individual differences in images and for adequate methods of determining these has persisted. This may indicate a growing suspicion that such individual differences may be more profitably stated without the incubus of "types."

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[12] He says, for example: "Es handelt sich weder um die den reproduzierten Vorstellungen anhaftenden Eigenschaften noch um die auf dem statistischen Wege zu ermittelnde Anzahl der verschiedenen Sinnesgebieten entstammenden Vorstellungen, sondern einzig und allein um ihr Zustandekommen, d. h. um die Wege, auf welchen ein Gegenstand, der prinzipiell auf verschiedene Wiese reproduziert werden kann, in Wirklichkeit zur Reproduktion gelangt." Segal (96, p. 214, *et al.*).

### D. FURTHER PROBLEMS OF IMAGERY.

Other and more advanced problems relative to imagery are attracting attention at present, but promise no adequate solution until there is more agreement on the prior questions of type differences and methods of determining them. There is, for example, the problem with which we started: that of discovering the causes of these differences, especially the question of the influence of education and training. Moreover, there is the many-sided question of the function of imagery. Has imagery as a whole any functional value peculiar to it, and do the different forms of imagery vary in effectiveness for different situations? To answer these questions some adequate methods of determining the presence of imagery are evidently prerequisites. Further problems of an educational bearing are also pertinent, but must wait, for experimental answers at least, until the preliminary questions are partially answered.

# III. EXPERIMENTAL SECTION.

## A. INTRODUCTORY STATEMENT.

The preceding survey indicates certain of the difficulties underlying experimental work on imagery. As our investigation was not designed primarily to evaluate and criticise the existing series of tests, we have not attempted a systematic working over of all those described. Our choice of tests has been determined by various considerations, among which are the following: First, we have received suggestions from the literature and have taken from this source the tests which seemed best supported experimentally and most free from theoretical objections. Further, we have thrown the emphasis on the determination of the kinds of imagery *used* in various situations, rather than on the discovery of what *could* be aroused for purposes of introspection.[1] We have likewise attempted to make the series as a whole comprehensive enough to include both verbal and object imagery over as wide a field as possible. In general, however, where it has been necessary to choose between a more extensive and a more intensive study we have selected the latter. Thus the field of our investigation has narrowed rather than broadened as the work progressed. We have also had in mind the choice of tests for diagnosis which might be used with slight modifications in the training series, in order that the two sets might be comparable.

We have not attempted, before experimentation, to group our tests as subjective or objective or both. Our general attitude has been to place the first dependence in every case on introspection. If the objective results confirm this, our confidence in the accuracy of the subject's introspection is strengthened. If the implications of the two seem contradictory, as they have in certain cases, we have had to leave the issue unsettled. In connection with every test we have also been on the lookout for any correlations which might exist between the introspections and the results obtained, with a view to the use of such tests as primarily objective in later work with untrained subjects. Moreover, we must admit that we have felt the need of all possible aids for the diagnosis, since we have recognized that, even with our well-trained subjects, introspection is far from infallible.

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[1] In the terminology suggested by Betts (15) we have attempted to test the "spontaneous" imagery rather than the "voluntary."

The extent to which we have attempted to make this introspection more exact by quizzing the subjects on special points would be difficult to indicate. As a rule, we have adopted the plan of first allowing the subject to report whatever seemed of significance to him. If this was particularly meagre, or failed to touch points with regard to which we especially wished information, we proceeded to question him along these lines. Where it has been possible to secure this information more indirectly: *i. e.*, by manipulation of tests, as indicated, for example, with reference to verbal imagery on p. 34 we have preferred this way, since the other always involves the danger of suggestion. We have not wished to present a stereotyped group of questions or "guide to introspection" partly because it tends to introduce a formality and artificiality which we wished to avoid, and partly because we found that many of the most interesting comments made were not anticipated by us, but were the spontaneous suggestions of the subjects. It would probably be impracticable to adopt the same attitude toward less well-trained subjects, however.

Since the demand on introspection was so great we used only subjects trained in introspection. There were eleven subjects, all either instructors or advanced graduate students in psychology, whom we shall designate as follows: A., Ad., C., G., Hs., H., P., S., Sun., T., V. Five of these—A., Ad., Hs., P., S.—are men; six—C., G., H., Sun., T., V.—are women. A., H. and S. had had special training in introspection on imagery through their participation in Miss Downey's investigation of handwriting (37).[2]

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[2] The tests, in a slightly modified form, were also given to two blind subjects, undergraduates in the University of Chicago. The results of these will be reported later in connection with the problem of training.

The experiments were conducted in the University of Chicago during the academic years of 1908-1909 and 1909-1910. No subject was available, however, during all of this time. A., G. and Sun. were used for part of the first year only; C., P., T. and V. for part of the second only; Ad., Hs., H. and S. for parts of both years. Sun., T. and V. were available for the shortest time and our work with them was therefore the least complete.

### B. DESCRIPTION OF TESTS.

The following condensed description is offered for convenience of reference. Further details with regard to each test are given in connection with the discussion of results. The tests are named by the operations performed, rather than by the imagery which they were designed to arouse, since the latter was often very variable and could not be prophesied. Our interest in imagery as *used* led us to base our experiments as far as possible upon common activities of the subjects, such as reading, spelling, mathematics, etc. In our application of the tests they have fallen into two groups, those for general diagnosis and those for more accurate investigation of specific problems. The present grouping, however, is not in any sense final, but represents the development of the tests to meet the needs of this situation. Certain of the tests here included in the former group might equally well be placed in the latter, if they were applied later in the series.

### 1. For General Diagnosis.

#### a. READING.

(1) Normal arrangement.

(a) Normal rate.

Twenty-one short passages were used (see Appendix, p. 139), some abstract in type and some very concrete, consisting of descriptive material referring to the various sensory fields. Both prose and poetry were included, as well as certain passages familiar to the subjects as set to music. The usual method was to give these to the subject in typewritten form and ask him to read them silently in as nearly as possible his normal manner. Introspection on the reading process was then requested, with sometimes a reproduction of the contents of the passage and introspection on this process. Two passages were read by the experimenter to the subject; one was read aloud by the subject to himself; and one by the subject to a listener.

The significance of this test lies entirely on the side of the introspective data which it furnishes. From this standpoint we have used it to some extent as a substitute for the questionary, which we have not included in our series.

(b) More rapid rates.

Twelve passages were given to be read at a rate more rapid than normal. Two rates were used: one where the subject was asked to read the passage as fast as he could actually see the words, whether he secured the sense or not—referred to as "most rapid visual scanning"; another where he was asked to read as fast as possible to secure the meaning—"most rapid for meaning." These rates were compared with those of normal reading for an equal number of passages, and the rates of the different subjects with one another. The time was measured by a stop watch. Reproductions of the passages were called for in each case, as a check on the carefulness of the reading.

While the introspection on these processes was valued for itself, the comparison of quantitative results was made to determine whether rapidity was correlated with the use of any particular form of imagery.

(2) With variations in the arrangements of words and letters.

Twelve passages were given in which the arrangement of words and letters was modified as follows: in 4, the whole passage was turned upside down; in 4, the order of letters in the word and of words in the line were reversed, so that they read from left to right—*e. g.*, yregami no stseT = Tests on imagery; in 4, mirror reading was called for. Two in each set were read silently and two read aloud. For all but the first of each series reproduction of the content was demanded. Introspection was reported in every case, and the time required for reading the passage recorded.

## b. SPELLING.

(1) Normal—Oral and written. With introspection.

(2) Backwards—Oral and written. With introspection.

Each word to be spelled from right to left instead of normally. Since a preliminary series indicated a certain amount of correlation between efficiency in this performance and the kind of imagery employed, an additional series of 30 words each for oral and written spelling was given, and the time for each word kept by a stop-watch. Moderately long and difficult words were given, since they brought out the differences between the subjects most strikingly.

### c. PRONOUNCING WORDS.

(1) Letters given in normal order.

(2) Letters given in reversed order: *e. g.,* d-e-s-r-e-v-e-r.

In both 1 and 2 the words were spelled orally, one letter at a time, the subject being required to speak the word as soon as possible after the completion of the spelling. As in the case of the spelling backwards an interesting correlation was suggested in 2, and accordingly two series of 30 words each were added. In Series I the letters were read at a rate of one per second; in Series II at a rate of two per second. The time between the speaking of the last letter by the experimenter and the pronouncing of the word by the subject was measured by means of a stop-watch. Introspection was called for as usual.

### d. MEMORY TESTS.

(1) Letters and numbers given (a) orally, (b) visually, in groups of six and of nine.

(2) Letters, numbers, words, symbols, geometrical figures, colors, etc., given visually in spatial forms, in groups of 9. (Method of Binet's letter squares.)

(3) Letters given visually, but reproduced in an order different from that in which they were presented. (Description follows.)

One preliminary series was given, consisting of eight twelve-letter groups; then two series of nine-letter groups. Each of the latter series consisted of eighteen cards, of which six were reproduced in the order read—by lines from left to right; four were reproduced by lines from right to left, beginning at the bottom; four by columns from top to bottom, beginning at the left; four by columns from bottom to top, beginning at the right. The subject knew that he would be asked to reproduce by one of these methods, but did not know which. When he had finished reading the letters a card was shown him with an arrow indicating the method to be used: thus, →, ←, ↑, ↓. (Series I and II differed merely in the directions given for reading the letters: In the former two readings of the series were requested, while in the latter eight seconds were allowed, regardless of the number of readings.) The results of the normal and the changed reproductions were compared, both as to accuracy and as to time, to determine the extent of the retardation caused by the change in order. A comparison was also made of the results for the different subjects with the changed orders to determine whether "visualizers" are more efficient in this performance, as has been claimed (See p. 9).

### e. DESCRIPTION OF PICTURES.

*Series I.* Twelve pictures—six colored and six uncolored—were shown to the subject for ten seconds each. He was then asked to describe the picture as fully as possible: immediately, in the case of the first four; after twenty-four hours, in the case of the second four; after forty-eight hours in the case of the last four.

*Series II.* Sixteen colored pictures were shown for ten seconds each. Of four an immediate description was requested: for four an interval of ten minutes was introduced before the description, during which time another task was performed: eight were given with distractions which will be described later.

For both series picture postal cards were used, since it was desired to have the pictures small enough so that every part might be seen in central vision during the time of exposure. A comparison was made between the accuracy and completeness of the description and the imagery reported by the subject. It was found a help in determining the accuracy of the subject's recollection to permit him to inspect the picture again after giving his report. By this means inaccuracies were often disclosed which would not have appeared in the mere verbal report.

*Series III.* Five pictures—colored—were presented to the subject with no knowledge on his part that a description would be requested. Four were puzzle pictures[3] given to him with instructions that he find the concealed objects. When this was accomplished a report was demanded. It was necessary to give all four pictures before calling for a report of any, in order that he might be kept in ignorance of the purpose of the test. The attention of the subject was called to the fifth picture—colored illustration (Taf. I) of the monograph by Urbantschitsch (111)—by a comment of the experimenter. When the subject had examined it for ten seconds the book was taken from him and he was asked for a report.

### f. DRAWING.

A series of simple patterns, cut in pasteboard was used. The subject, with eyes closed, traced these by running a pencil around the grooves. The number of times which this was allowed varied with the difficulty of the pattern. The subject then reproduced the drawing—with eyes still closed—first in the same position, then as turned clockwise through 90, 180 and 270 degrees.

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[3] The cards used were "Sheahan's Pleasing Puzzle Cards," published by M. T. Sheahan, Boston. The following numbers were used, given in the following order: 1306, 1303, 1308, 1307.

### g. LISTS OF WORDS GROUPED ACCORDING TO SOUND OR SPELLING OR BOTH.

(1) Grouped according to sound—Rhyming lists.

A word was spoken and one minute allowed, during which the subject wrote all the words which occurred to him, which rhymed with the given word. Words of different lengths and proper names were allowed.

*E. g.*, Word given—home: List—dome, foam, loam, metronome, comb, etc.

(2) Grouped according to spelling.

Three final letters of a word were given and one minute allowed, during which the subject wrote all the words which occurred to him, which ended with these letters.

*E. g.*, Ending given—one: List—bone, cone, done, gone, lone, none, etc.

The following endings were used: ough, ose, ome, ave, one, ate, ine, ore.

(3) Combination of 1 and 2.

An ending was given as for 2, but the subject was required to group words in columns according to sounds. Two minutes were allowed for each list.

The following endings were given: are, ove, oth, ear, ead.

*E. g.*, Ending—ove: Lists—

| | | |
|---|---|---|
| hove | dove | prove |
| dove | love | behoove |
| stove | shove | move |

### h. MATHEMATICAL PROBLEMS.

(1) Normal procedure.

Problems in mental arithmetic—addition, subtraction, multiplication and division—were given, some orally and some visually. The subject performed the operation and reported upon the process. Time records were also kept.

(2) In Roman notation.

More difficult problems were given in Roman notation: *e. g.*, CXLIV × LXII = ?—with directions to the subject that he must make all records in Roman notation. Time records were kept, as well as the usual introspective reports.

### i. ELEMENTARY PHYSICS PROBLEMS.

Eleven problems, taken from an elementary physics text—Millikan and Gale—were given to the subjects to solve and explain, with introspection on the process.

### 2. For More Accurate Analysis of Type.

#### a. Tests not involving distractions.

##### (1) MEMORY TESTS.

(a) Series of numbers in both Roman and Arabic numerals:

*E. g.*, 6 V 9
X 3 VII
2 8 IV

10 seconds' exposure.

(b) Series of words pronounced alike but spelled differently:

*E. g.*, cent, rays, cite.
raise, site, sent.
sight, raze, scent.

15 seconds' exposure.

(c) Series of words spelled alike but pronounced differently. Read by experimenter to subject and reproduced orally:

*E. g.*, wind, lives, row.
bass, mall, lives.
row, wind, bass.

The accuracy of reproduction was measured in every case and compared with the introspective reports. a and b were introduced as a stimulus to visual imagery; c as a stimulus to auditory. The use of the tests as objective was considered.

##### (2) MEMORY AND RECOGNITION TESTS.

In the following tests, tints and shades of colors, as closely graded as it was possible to find them, were used. The materials were colored papers found in the sample books prepared by Milton Bradley Company and Prang Company. The latter were more satisfactory for this purpose, since they furnished a larger number of closely graded sets. The former were used as far as possible, however, since publication of the latter has been discontinued, so that it is impossible to duplicate the Prang colors.

(a) Matching colors.

One colored paper was exposed on a white background for ten seconds. A series of ten similar shades, including this one, was then shown, and the subject was required to select the original color from the series. Careful introspection on the process of selection was demanded, and a comparison was made of the records of the various subjects, in search of objective indications of imagery used. (This test is practically identical with one used by Segal (96).)

(b) Sorting colors.

Four shades of one color were placed in the four quadrants of a diagram like the following —+— on a card 3x2 in. Cards were prepared—3x2 in.—, by pasting on each a rectangle —9/8x7/8 in.—of one of the colors used. Four such cards were prepared for each shade. The subject was shown the original diagram for ten seconds. He was then given a pack of sixteen cards, containing four of each shade, and was required to sort these in a larger diagram of four quadrants placed on the table before him. Each card was turned face down in this sorting, so that it might not serve as a guide for the placing of the following cards. If mistakes were made, the process was repeated until correctly performed. In two series—the preliminary and the Milton Bradley (five groups)—the subject was also required to sort the colors as they would be arranged if the diagram were turned clockwise through 90 degrees. In some cases a re-sorting was called for after 24 or 48 hours. In the Prang series (seven groups) several other variations were introduced.

Introspection was considered of first importance here, but the availability of the test for objective uses was also contemplated. To this end, the time required for each sorting, the number of sortings necessary and the accuracy of each sorting were all recorded as indications of efficiency.

b. Tests involving distractions.

### (1) DISTRACTIONS USED.

(a) For visual.
  (1) Tracing or copying pattern.
  (2) Sorting colors with diagram in sight.
(b) For articulatory, vocal-motor, etc.
  (1) Pressing tongue against upper gums.
  (2) Exhaling slowly.
  (3) Swallowing. The subject held between his teeth a glass tube, through which water was furnished steadily but at a reasonable rate by means of a syphon.

(c) For auditory and articulatory.
  (1) Sounding a letter continuously—a, e, o, s, etc.
  (2) Counting silently or aloud.
  (3) Saying alphabet silently or aloud.
  (4) Reciting familiar verse.
  (5) Whistling.

### (2) TESTS PERFORMED WITH ABOVE DISTRACTIONS.

Tests already described were used with these distractions, as follows:

(a) Reading.
  (1) Listening to passage. Distractions: swallowing, counting, copying pattern, sorting colors.
  (2) Reading to self. Distractions: counting, whistling.
(b) Spelling backwards. Distractions: swallowing, counting, saying alphabet.
(c) Memorizing.
  (1) Words pronounced alike but spelled differently. Distractions: swallowing, whistling.
  (2) Words spelled alike but pronounced differently. Distractions: swallowing, whistling, saying a—, saying alphabet.
  (3) Numerals—Roman and Arabic. Distraction: swallowing.
(d) Description of pictures. Distractions: whistling, reciting "Peter Piper picked a peck of pickled peppers."
(e) Forming lists of words ending in same letters, grouped by sounds. Distractions: swallowing, counting, saying alphabet, saying a—, e—, etc.

## C. EXPERIMENTAL DATA.

1. Preliminary tests.

### a. READING.

(1) Normal arrangement of letters.

Nature of Passages. The passages given were quite diverse in character. According to subject-matter and form they fall into several groups, as follows: (Numbers refer to number of passage in series of 33.)

### *Abstract in Character—Prose.*

From psychological texts: 1-4, 8, 10, 19, 23.
From elementary physics text: 14, 15, 21, 22, 25.
From Colonial History (Thwaites): 30-32.
From Ethics text (Dewey and Tufts): 33.
In essay style: 13 (Chesterton), 16 (Stevenson).

### *More Descriptive Passages.*

#### Prose.

5 and 9: Thackeray: Vanity Fair.
11: Kipling: Elephant's Child (in Just So Stories).
17: Henry James: Golden Bowl.
24: Meredith: Ordeal of Richard Feverel.
27: Translation from Homer—five paragraphs.

#### Verse.

6: Kipling: Mandalay.
7: Keats: Saint Agnes' Eve—first two verses.
12: Stephen Phillips: Ulysses.
18: Shelley: Skylark.
20: Gray: Elegy in a Country Churchyard.
26: Herford: Some Geese.
28: Lang: Odyssey.
29: Dixie.

(For representative passages from this list, see Appendix, p. 139 ff.)

This heterogeneous collection was made with the desire to stimulate as wide a range of imagery processes as possible, and to observe the reactions with very different kinds of materials. A number of passages originally in the list have been dropped, since they added nothing of importance. We are convinced by our experience that it is less easy than it seems to select a series of passages whose descriptions call out the various forms of illustrative imagery. Simple reference to a particular sort of material is not sufficient as a rule, even for persons who use that imagery with ease. The references must be so skillfully introduced and so effectively phrased that they carry the reader beyond the mere words. It has seemed easier to find such passages for visual materials than for sounds, if we disregard the sounds of the *words,* which may assume importance in expressing emotion, giving rhythm, producing onomatopoetic effects, etc. In the above list there are several passages which suggest only visual objects with no reference to other sense fields, while there is no case of the reverse. It will not be surprising, therefore, if we find a larger proportion of visual illustrative images than of any other, nor will it be *necessarily* an indication of strongly visual subjects. No. 20 is probably the best balanced passage, for both vision and sound, though Nos. 18, 27 and 28 have some vivid references to sounds.

PROCEDURE. The various modes of procedure used were distributed thus: (1) *Read silently at normal rate. Content reproduced.*[4]—Nos. 1, 7, 9, 10, 19, 31. (2) *Read silently at two faster rates. Content reproduced.*—Nos. 4, 5, 13, 15, 16, 21, 22, 30, 32, 33. (3) *Read silently at normal rate. No reproduction.* —Nos. 6, 8, 11, 14, 17, 18, 20, 23, 24, 25, 26, 27, 28, 29. (Slight deviations from the usual method occurred with the following passages: In 14 the subject was directed to put himself in the attitude of student about to perform the experiment; in 17 he was asked to give special attention to the passage as significant point in the novel; in 20 he was asked to make an effort to arouse imagery, in so far as this could be done without breaking up the reading, since the material was so familiar that otherwise it might fail to enlist the attention at all; in 23 he was asked to give his own personal reaction on the point made by the author.) (4) *Passage read aloud by experimenter.*—3, 12. (Reproduction for 3, not for 12.) (5) *Passage read aloud by subject.*—2, 27. (Reproduction for 2, not for 27.)

RESULTS. On the introspective side there were three main things which we tried to secure from these tests: (a) An account of the verbal imagery used in reading and in hearing passages of various types; (b) A report of the illustrative imagery most commonly used and most readily precipitated by description; (c) A statement of the nature and amounts of these two factors in recall. From the standpoint of the possible value of the tests as objective indications of form of imagery we have tried to determine (d) whether the type of imagery used can be inferred from the contents of the words used in reproduction, and (e) whether speed of reading is correlated with the use of any particular type of imagery.

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[4] Because of shortness of time several omissions were made with the later subjects. No. 2 was omitted altogether with C., P., T. and V.; reproduction of passages 7, 9 and 10 was not called for from C., P. and T., while V. was asked to reproduce only 10 and 13.

### (a) VERBAL IMAGERY USED IN READING AND IN LISTENING TO PASSAGE.

*Silent Reading.* It must be remembered that in all cases of silent reading visual perceptual material is present, so that the need of visual verbal imagery would be slight. A lack of this, therefore, under these conditions, does not indicate that the subject cannot command it. The question is rather whether the subject reads with complete dependence upon the visual perceptual material (words), or whether he finds it necessary to use some form of the auditory-vocal-motor complex.[5] If the latter prove true for all subjects there remains the problem of observing the differences between the different subjects in the nature and relative amounts of these elements.

In answering this question experimentally we have had to be on our guard against the tendency of many subjects to ignore the issue entirely. If a passage of a general descriptive character be given, the subject frequently mentions only the *illustrative* imagery, or comments on the lack of it, if absent, by saying "no imagery." We have tried to counteract this tendency in several ways, aside from the direct attempt to extract further information as to the words by questioning.

The use of passages such as Nos. 9 and 11, which involve dialogue of an emphatic character, tends to secure recognition for the verbal imagery as such, though in an extreme form. In the latter especially, where there are the peculiar words which the Elephant's Child speaks through his nose—"Led go! You are hurtig be!" and "This is too butch for be!"—almost all of the subjects became conscious of more or less extensive articulatory tendencies, or else of emphasis on the auditory verbal imagery. The poetry as a whole tended to call attention to the use of the auditory and vocal-motor forms, as the subjects, almost universally, began to comment on their appreciation of the rhythm. This was strikingly true for No. 6 (Mandalay), which has a very swinging movement, and was also familiar to most of them. The tendency here was for the majority of them to comment on the sheer verbal swing of the thing and not to develop any of the illustrative imagery. For those who were familiar with the passage as set to music, imagery for the tune appeared at once. In 29 (Dixie), also, the words tended to absorb all the attention to the exclusion of illustrative material. Here they were in every case imaged as a part of the tune. Several of the subjects remarked in despair: "I can't do it. It is simply impossible to *read* it. It sings itself off every time I try."

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[5] In the following discussion we have used sometimes the above expression (vocal-motor) and sometimes the term "articulatory" with no intentional difference in meaning. The difference in usage results from copying the terminology of the different subjects.

In such ways as these, then, the fact that verbal imagery might have an intrinsic importance was emphasized for the subjects. After they had recognized it in these more extreme cases they were more ready to detect it in ordinary passages. We may say for the passages as a whole that all the subjects reported to some degree an accompaniment of one or another of the following forms: Auditory imagery, vocal-motor factors (imagery, movements or tendencies to movement), or a complex of auditory and vocal-motor. For most of the subjects this was a constant accompaniment and constituted a part of what the subject meant by "reading." With A. and C., while no passages were read at normal rate without some of this, transitions were often made without the use of it. It is likewise true that G. and Sun. fail to report auditory or vocal-motor for many of the passages, especially the earlier ones. We could not be sure, however, that this was not due to the fact that attention in the introspection was attracted elsewhere. It seemed significant that Sun., after she once began reporting "inaudible pronouncing." [6] observed it in almost all the later passages. Her comments on the rhythm and the "liquid sounds" in 6, on the disagreeable rhythm and "the chopped-off effect" produced by the hyphens in 26, and other remarks of like character indicate that the articulatory factor is by no means a negligible element in her reading. G.'s case is somewhat more puzzling, as she seldom reports with assurance a steady accompaniment of the auditory or vocal-motor sort, though she frequently reports this for occasional words. Her introspections show a very marked interest in her æsthetic reactions to the passages, and it may be that this distracted her attention from the mechanics of the immediate apprehension of the material. (Most of the subjects reported that this introspection was far from easy if they followed with any success the directions to read "naturally.") Or it may be that she actually read a large part of the material with nothing further, as to the words, than direct visual apprehension.

For the more rapid reading the majority of the subjects showed a tendency to slur or omit the auditory-vocal-motor formulation. Usually this meant either skipping in the pronunciation, from one word to another, or blurring all the words. Certain of the subjects (A., C., G., Sun., T.) reported occasionally an almost complete absence of anything but the visual perceptual apprehension.

As far as the analysis of the auditory-vocal-motor complex is concerned the data furnished by these tests are decidedly rough. Three of the subjects (H., S., Sun.) have expressed themselves as uncertain as to whether they ever have any *auditory* verbal imagery, but are strongly of the opinion that they do not. All the subjects have asserted that they were unable to tell with certainty how much of the vocal-motor factor is *imagery* and how much is actual *sensation* aroused by movements of the vocal organs, more or less extensive. In the case of Hs. there was no question that such movements did occur in a highly developed form. Lip movements were evident to the observer and Hs.

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[6] This change appeared also in memory tests carried on simultaneously with these.

asserts that these are accompanied normally by movements of the tongue and throat. He is not sure, however, that these are not accompanied and supplemented by *imagery* of such movements. S., on the other hand, appears to the observer to be reading with no movements of the lips and throat, yet he is very confident that movements are present, chiefly in the back of the tongue and the post-nasal passages. As to the presence of motor *imagery* he is exceedingly dubious. C., who reports as a rule, "auditory-motor" imagery, declares that the whole *motor* element is slight and questioned, but that, so far as she can determine, it is far more like *imagery* than like *movements*. These cases are typical of the problem which confronts us. We have tried to carry this analysis further at a later point, but for the present our references to the motor "factors" are left in the same ambiguous form in which we have received them from our subjects. Our excuse for including articulatory *movements* and *sensations* in a discussion of *imagery* is just this fact, that they are so closely involved in the complex, that the subjects find themselves unable to dissociate them for purposes of introspection. C., P. and T. are quite positive that their verbal form in reading is predominantly *auditory* with a minimum of vocal-motor or none at all.

For excerpts from introspective reports, illustrating these points, see Appendix, p. 144 ff.

*Listening.* The reports given by the various subjects on the two passages which were read to them may be very briefly summarized. In general this procedure was less pleasing to the subjects than the preceding, partly because they were more used to handling material in the latter way and felt it to be more under their control, and partly because the experimenter's reading did not altogether satisfy their demands. More passages should be used in order to make the observations of much value.

The report most frequently given was to the effect that no *verbal imagery* was used, but that the auditory perceptual material with more or less illustrative imagery of various sorts was sufficient. The following subjects reported this: A. (for No. 12), G. (for No. 12), Hs., P., S., T., V. Several subjects reported a tendency to repeat the words after the reader—at least the more important words. These subjects were A. (for No. 3), Ad., H. (This tendency would probably have been emphasized by the use of more difficult material.) T. observed a tendency to hear the words in her own voice. Three of the subjects showed a tendency to visualize some of the words as they were read. These were C., G. (for No. 3), Sun. None reported a constant accompaniment of visual verbal imagery.

### (b) ILLUSTRATIVE IMAGERY.

We have already commented on the fact that the nature of the illustrative imagery is not determined wholly by the possible suggestions of the words used. We shall present evidence of this in this section. We must also insist, on the basis of our results, that it is not determined solely by the possible range of a given subject's imagery, and that accordingly the range reported in a series of tests such as this, even assuming vivid descriptions in the various fields, cannot be taken as comprehensive in diagnostic value. Certain subjects, who *can* summon images of several kinds under other conditions, normally use very little but the words with their clang and meaning when reading even descriptive material, unless the point of the passage is made somehow to turn on the presence of such imagery.

Instead of allowing this tendency (to sheer verbal reading) to take its course, however, we have rather obscured it by our choice and manipulation of material. In the first place we tried to select passages containing as vivid and effective references as possible to various sensory fields. If we found with our first subjects that certain of these were proving generally unsuccessful in stimulating the desired imagery, they were dropped from the list and others substituted. We have also introduced certain passages which apparently demanded the use of some particular imagery to get the point at all: *e. g.,* 14, 17, 23. (This does not mean that even in these cases we did not find some of the subjects quite expert in evading this demand.) In one case (20) we have asked the subject to make a special effort to develop the imagery suggested. In general, too, many of the subjects reported themselves as quite sensitive to the experimental conditions, so that a certain amount of imagery was more or less artificially stimulated: *i. e.,* would not have appeared in normal reading, so far as they could tell.

In addition to this general limitation there were other more specific difficulties which met us in the interpretation of these tests. As in the case of verbal imagery we must recognize that the introspective task is one of very considerable difficulty, since we have asked the subject to give himself over to the task in hand and not to take the introspective attitude until afterwards. We need not be surprised, therefore, if our subjects find themselves unable to report in detail the processes involved in the reading. Indeed, some of our best introspectionists are especially apt to feel this difficulty, since they are most apt to detect a confusion between the imagery which appears during reading and that which appears as they linger over the passage in the attempt to remember the former. Moreover, the ease of just this confusion lessens the possibility of eliciting accurate information from the subject by questioning. We have not, therefore, considered these results as a *census* of the imagery roused by these passages, but have rather taken whatever positive information they give us as so much gain and have made comparisons on the basis of rough and striking differences rather than on that of minute numerical discrepancies.

Another factor which has added to our problem is the difficulty of determining whether scantiness of a certain form of imagery in these tests is an indication that that is an unfavored form, or whether it is due to the fact that the subject normally uses a minimum of accompanying imagery *in the reading process.* The solution of this problem would, of course, be easier if the stimuli to different forms of imagery were more evenly distributed in our selections. Even as it is, it is much easier to reach a decision in the case of a subject who is notably lacking in one form, though well primed for certain others, than in that of one who is quite lacking in the majority of strictly sensorial forms of imagery: *i. e.,* who is predominantly motor in type. V. and H. are representatives of these two forms. V., though reporting relatively little visual imagery—vague and fragmentary at best—gives evidence of such an exuberance of certain other forms—kinæsthetic, tactual, temperature, etc.—that we seem justified in ascribing the scantiness of the former type to relative deficiency of visual imagery. H., on the other hand, shows no such compensation in other fields, but seems rather satisfied with the verbal formulation plus certain motor responses and attitudes. If we press the questions as to what she *can* get we receive a similar reply: *viz.,* most of these images are summoned with difficulty, if at all, and in vague and unsatisfactory form. The results as a whole, therefore, indicate an actual scantiness in imagery endowment. With A., on the other hand, while the report is somewhat similar on the face of it, there are certain significant differences. In the passages which represent variations from straight reading—where, for example, more careful reading is called for, etc.—visual and auditory imagery appear in considerable abundance, especially the former. When asked what he *can* get, again he calls them up with great readiness. We apparently have good grounds in his case, therefore, for believing that scantiness of reported imagery is indicative of the nature of his reading habit rather than of actual deficiency in these forms, especially as we find confirmation of this diagnosis from our other tests.

It may help to clear the ground for our discussion of variations in form of imagery used if we first summarize our observations as to individual differences in profusion or scantiness of illustrative imagery in general during the reading process. Exact comparison is impossible from the nature of our data, but the following statement indicates the most striking differences.

A.—Tendency to use a minimum of illustrative imagery during normal reading. This tendency much increased in rapid reading.

✓ Ad.—Much like A. in this respect, though with apparently somewhat more imagery during the reading process.

C.—Vis. imagery quite profuse as a rule, others moderate in amount.

G.—More imagery than A., but less than C. More apt to be sporadic and fragmentary. Considerable reference to motor attitude of appreciation or response.

Hs.—Very abundant imagery.

H.—Strikingly little imagery.

P.—Fair amount of imagery, but usually vague and indefinite—described as the kind which is just about to develop into a good image.

S.—Apparently the most profuse and vivid imagery (of a vis. sort) of any of our subjects. Adds many details to make picture complete: *e. g.,* the owl, of No. 7, is "sitting on a limb, very fluffy with feathers slightly ruffled on the windy side," and the rabbit of the same passage "took a short mincing jump or two with left hind leg in the air."

Sun.—Illustrative imagery in general very scanty.

T.—Illustrative imagery scanty, except as she turned her attention to it, and even then it was not vivid and detailed.

V.—Profusion of images other than visual. Latter relatively few and exceedingly unsatisfactory.

If we turn now to the question, somewhat more pertinent to our problem, as to the relative amounts of the various kinds of imagery aroused in the different subjects, we find a certain amount of data furnished by these tests. Again we are reminded that an accurate comparison, based on an enumeration of all the instances of imagery reported, would be without significance and entirely unwarranted, because of the character of our passages and the lack of exactness in the introspective reports. Even with these restrictions, however, certain instructive facts appear with regard to the prevalence of these forms in typical cases. In the first place, one positive result, which is of considerable importance for our general diagnosis, is the discovery that none of our subjects report an absolute lack of *visual illustrative* imagery. Moreover, all but three (H., S. and Sun.) report at least occasional instances of *auditory,* and these three express themselves not as absolutely certain of its absence, but rather as exceedingly dubious of its presence.

With regard to the other forms of possible imagery the best we can do is to note their presence or absence in the few cases of more or less vivid description. *Cold,* for example, is introduced in a very striking way in No. 7, yet only one subject (V.) reported any *temperature* imagery, though some observed organic reactions (shivering, etc.), or visual representation of its effects. *Cold* is also an element of the situation in No. 24, in connection with the wet, and in No. 28, in the reference to the wind, yet we find it mentioned by only one subject (S.) in the former case and then as questioned, and in the latter case only three (Sun., T. and V.) report it. *Warmth* is mentioned in several passages but appears most vividly in No. 24, where it appears twice—in the reference to the heat of the night and in the account of the touch of the warm animal—yet none of the subjects report it for the first case and only four (C., G., S. and Sun.) for the latter. (The latter part of the passage was omitted, however, with T.) For *contact,* No. 24 again gives us the best instance. Here there are two very striking references—the touching of the animal and the feeling of the tongue on the palm. Most of the subjects (all but Ad., H. and Sun.) get at least one of these and all commented on the cleverness of the description. *Olfactory* material is fairly well suggested in at least four selections—Nos. 12, 23, 24, 28—yet there is noticeably little imagery aroused. In 12, two (C. and S.) report it as questioned; in 23, three (Ad., H. and V.) report it with assurance, and six (A., G., Hs., P., S. and T.) as questioned; in 24 and 28, V. is the only one who finds these images present, but with her they are very abundant. Hs., S. and V. note *gustatory* imagery for the salt in 28.

With *kinæsthetic* and *organic* material we have the same sort of problem that we had with the vocal-motor, that of distinguishing between imagery and actual reinstatement of sensations. Again, aside from the certainty that in many cases it is the latter, we have had to leave the problem unsolved. In one form or another these elements play a considerable part in these tests, not so often as a result of direct description as accessory to or substitute for some other form: *e. g.,* the tendency to sniff or widen the nostrils in place of an actual olfactory sensation All the subjects but two (S. and Sun.) experienced some form of disagreeable organic response for the first paragraph in No. 8. Direct description of emotional reactions seemed less effective, as indicated by the fact that only two of the subjects (Hs. and V.) noted such reinstatement in No. 10, and only one (V.) for No. 19. The familiarity of the material—conventional description of the expression of emotions—may have been partially responsible for this. Organic response, usually in the way of an æsthetic reaction to the material, was very frequently reported. G. says, for example, for No. 7, "When a phrase or line is as pleasant as this I involuntarily lift my face up." Such material, however, is rather aside from the main trend of our investigation, and has, therefore, been omitted in our records.

Such, then, are some of the indications of our data with reference to the prevalence of forms of imagery other than auditory and visual. On the whole they seem to signify a lesser degree of suggestibility to most of these forms than to visual and auditory imagery on the part of all subjects except V.

With regard to the relative ease with which visual and auditory imagery are stimulated some impression may be gained by a comparison of the introspections on certain passages in which auditory imagery has an approximately even chance with the visual: *e. g.*, Nos. 20, 23, 27. Investigation shows a decided preponderance of visual imagery over the auditory for the majority of subjects. In no case did the auditory images surpass the visual in amount. This result was particularly striking for passage 23 (see Appendix, p. 141), since the attention was supposed to be centered here on the element of sound.

The results for these three passages are fairly representative of the relationship which has appeared throughout these tests. Again and again where auditory imagery is suggested only the visual image of the sounding object appears. In certain cases the significance of a phrase is even changed to favor the visual rather than the auditory. Thus, both G. and T. report, independently of one another, that the "low-crying birds" of passage 12 were thought of as "low-flying birds," with appropriate visual imagery. G. also transformed the "drowsy tinklings" of No. 20 into twinklings of star lights.

In general, then, we may say, for the majority of our subjects, that, under the conditions of reading and listening, a greater susceptibility is shown to the suggestion of accompanying visual imagery than to that of accompanying sounds.[7] We cannot state with certainty the explanation of this, but in all probability several causes conspire together to produce the effect. It may be true, as Segal (96), Meumann (74) and others have said, that *visual* is the prevailing form of concrete imagery throughout the thinking of the majority of persons, because visual objects have a much greater practical significance for most of us than do sounds. It may also be due to the fact that, while we constantly experience visual objects which give no sound, we seldom experience sounds without some sounding object which can be or has been seen. In the reading process, the fact that most of our subjects have a running accompaniment of auditory-vocal-motor verbal imagery may help to account for the deficiency in auditory concrete imagery, since one of these may inhibit the other. Another consideration seems pertinent, that sounds may get a fairly adequate representation through changes in the inflection in reading and through the onomatopoetic effect of many of the words—a representation which the visual entirely lacks.

### (c) IMAGERY IN RECALL.

For the recall and reproduction of any passage there were several possibilities: (1) A purely verbal recall, which might be vis., aud., artic., or a combination of these in any proportions; (2) predominantly illustrative imagery of the various sorts; (3) a combination of verbal and illustrative. We may expect that variations may appear both as indications of individual differences and as a result of differences in the character of the passages, possibly also with changes in the mode of presentation. In most cases the direction given the subject was simply to reproduce the content of the passage without regard to the exact phraseology. In one case (No. 26) he was asked to learn the verse by heart if possible in three readings, and in another case he was to write a stanza of "The Star Spangled Banner" with which he was supposedly (!) familiar.

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[7] Kuhlmann (61) notes a similar point in comparing the process of memorizing sounds with that of memorizing visual objects. He says: "Any one who has had his attention called to the matter will have observed the very striking difference in the amount and nature of associated imagery when he is looking at things when they are silent and when he is listening to the sounds they make when he cannot see them. . . In the previous study on the memory of pictures of familiar objects there was never the slightest tendency to auditory imagery while memorizing a group of pictures, and auditory imagery entered only in a very few individual instances in the recall of pictures after long time intervals. . . . In the second part of this study visual imagery was never entirely absent in listening to the sounds for the first few times, nor in the recalls immediately after hearing them," etc.

We shall not go into the same amount of detail in reference to these results as we have in the preceding discussions, since we have indicated there the most striking of the individual peculiarities. The following points, however, seem worthy of note and may be indicated in schematic form, thus:

TABLE I.

*I. Verbal Imagery as Reported in Recall.*

| *Imagery used.* | *Subjects reporting it.* |
|---|---|
| Aud. (alone). | T. (Very rare vis.), V. (One vis.) |
| " with voc.-mot. | Ad. |
| " " vis. | G (?) (Vis. seems more important. Not sure of aud.)<br>P (?) (Not clear from introspection.) |
| " " voc.-mot. and vis. | A. (Aud.-voc.-mot. predominating.)<br>C. (Vis. predom.)<br>Hs. (All in marked degree. Lip-mot. very abundant.) |
| Vocal-mot. (alone). | H. (Occasional vis.) |
| " " with vis. | S., Sun. |
| Vis. (alone). | None. (Possibly G.) |
| " (in one of the above combinations.) | A., C., G., P., S., Sun. |

*II. Illustrative imagery reported as aid.*

Some form reported by A., C., G., Hs., S., Sun.

### (d) INFERENCE FROM CONTENTS OF WORDS USED TO TYPE OF IMAGERY.

Little need be said on this point here, since we have presented our evidence in the foregoing discussions of illustrative imagery in reading and in recall. If we accept the introspections of our subjects, we may assert that, as far as reading and reproduction of descriptive passages are concerned, we are by no means justified in inferring from the use of a word of a given sensory content that imagery belonging to that sensory field is present. The large number of passages reproduced with nothing but verbal imagery present, as well as the cases where the imagery least directly suggested is substituted for the imagery more obviously appealed to (*Cf.* discussion of vis. and aud. imagery above, p. 43) are cases in point.

### (e) CORRELATION BETWEEN SPEED OF READING AND TYPE OF IMAGERY.

The statement is sometimes made that, other things being equal, "visualizers" are more rapid readers than others, since they are not delayed by the auditory-vocal-motor accompaniment. Though uncertain as to how much might be involved in the "other things being equal," we have thought it worth while to see whether any such correlation appeared with our subjects for the three rates described above (p. 25). The result has been a lack of correlation for any of the three rates and an indication that other factors are sufficient to obscure this tendency, provided it exists.[8] One exception appears, however, in the case of Hs., who depends constantly on the accompaniment of lip movement. For all three forms he is decidedly the slowest, a fact which he himself attributes largely to the fact that he is so dependent upon this lip-motor accompaniment. H., on the other hand, who is also decidedly motor for reading, but not in so overt a form, is one of the more rapid readers.

(2) With variations in arrangement of words and letters.

As a whole these passages did not add much to our previous analysis of the imagery side of the reading consciousness, except by furnishing cases where the words themselves presented a problem to the subject and were therefore thrown into prominence. For all subjects it was true that the apprehension of meaning was reduced in the effort to get the words into comprehensible form, though the latter process presented more difficulties for some than for others. The difficulty or ease did not seem to be correlated with the kind of imagery used.

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[8] As to other possible factors, see, for example, Dearborn's discussion on the relation between rapidity of reading and the nature of the eye-movement habit, in "The Psychology of Reading" (35).

In general we may say that this procedure tends to throw the auditory-vocal-motor combination into prominence and to suppress the visual. In this respect it has just the reverse effect from the rapid reading, which tended to reduce the subject to dependence upon the visual impression with the elimination of other factors. This appears, too, in spite of the fact that there is a certain premium placed on visual imagery because the words look so queer that all the subjects express the desire to get them as they ought to look, to turn them around. In many cases this results in a muscular twist of the head or the whole body. In a few cases it also stimulates a visual image of the word in its correct form. H. finds this to some extent (Sun. (?) also in a few cases). P. notes it for a few words; P. and T. report some tendency to invert individual letters, in order to make out what they are. H. attempted to do this but was unsuccessful (often to a degree very entertaining to the experimenter). G. used visual imagery of the letters, together with auditory and vocal-motor in first getting the word, which then came in auditory terms. All the rest—A., Ad., C., S., Sun. (?) and V.—report no visual verbal imagery during the reading.

In the recall auditory-vocal-motor factors are present in about the same degree as in recall of normal passages. As to the visual images, Ad., H. and T. report none of any sort, and A. reports only visual of the page inverted. C., G., Hs., S. and Sun. report more or less visual of the words as they appeared for reading, and P. notes a certain amount of vague visual which does not seem to be any help to him.

(3) Summary of results of reading tests.

(1) All subjects report, for silent reading, the presence of some portion of the auditory-vocal-motor complex for at least a part of the reading: *i. e.*, all subjects certainly *can* use this on occasion. Visual verbal is almost entirely lacking for this procedure—possibly present for G. and S. Rapid reading produces in the majority of cases a reduction and slurring of the auditory-

vocal-motor, and in some cases a complete elimination of it. Variations in the arrangement of letters tend to emphasize this complex.

(2) Visual verbal, which was noticeably absent in the above case, appears to some degree while listening, with three subjects—C., G. and Sun.—and, more abundantly, while reproducing content of passage for A., C., G., Hs., P., S. and Sun. For the other subjects it is reported as so slight and uncertain as to be negligible. In the passages with varied arrangement visual imagery of the words was reported either for reading or recall by the following: C., G., Hs., P., S., Sun. To state it in a negative way, taking all these tests together the following subjects have failed to discover an appreciable amount of visual verbal imagery: Ad., H., T., V.

(3) Some illustrative imagery appeared with all subjects. None reported a complete absence of visual, though there were striking variations in amount, from S., C. and Hs., who got profuse, vivid and detailed imagery, often when it was only suggested by a metaphor, through A., Ad. and P., who tended to have slight, schematic and fleeting imagery, to H., T. and V., who got almost no visual and obtained what they did apparently chiefly as a result of the conditions artificially imposed to stimulate it. For the subjects as a whole it seems true that there was a greater tendency to respond to a suggestion of visual imagery than to one for any other sensory field. V. represents the most striking variation from this tendency.

(4) From (1), (2) and (3) it is clear that we cannot claim to have found genuinely one-sided subjects, even judging from this one set of tests and in spite of the fact that we have chosen ✓ the most "imageless" subjects available. The results also indicate a general confirmation of Meumann's claim that the majority of persons are auditory or auditory-vocal-motor for words, ✓ but predominantly visual in their non-verbal thinking. This confirmation, however, is subject to the limitations already noted, arising from the fact that our material is not of a character to stimulate all fields equally.

(5) Our results are negative with reference to the possibility

of inferring the form of imagery necessarily used from the content of the words. We found that one could read and enjoy a highly descriptive passage without arousing any of the possible non-verbal imagery, and that one could reproduce such a passage quite accurately without dependence on such imagery.

(6) No correlation appeared between rate of reading and the type of control used, except in the case of Hs., where the indication was that overt lip-movements tend to retard the rate of reading.

### b. SPELLING.

(1) *Normal.*

In the spelling tests our problem is simplified as compared with that of the preceding tests, since we have here a case where the *form* of the word (visual, auditory or motor) is all that need be considered. We shall, therefore, have only the verbal imagery to discuss, including in this *letter* imagery as well as *word* imagery proper.

The normal spelling was passed over very rapidly. Both oral and written spelling were observed, one list of five words and one of seven being given for each. The former consisted of polysyllables chosen at haphazard, the latter of words chosen because of a similarity in sound of the first syllables, but a difference in spelling. It was thought that the latter might call out more visual imagery. The list for written spelling was the following: Scientific, psychology, sigh, sizable, schism, sister, sizzle.

The chief difficulty noted in the introspection arose from the fact that there was a strong tendency for the process to run off as a hand-motor or vocal-motor automatism, or at least to approximate this. Some difficulty in the spelling seemed necessary with many subjects to bring to consciousness any form of control. The main points of interest with regard to the imagery processes of the given subjects in normal spelling are indicated in brief in the following table. Where several forms are reported, but one is described as more prominent, the latter is given in italics.

## TABLE II.

*Introspection on Normal Spelling.*

| *Subj.* | *Oral.* | *Written.* |
|---|---|---|
| A. | *1. Vis. | 1. *Aud.* of word and of letters. Vis. occasional. |
| | 2. Vis. | 2. *Aud.* and *vis.* Think latter more important. |
| Ad. | 1. Aud. (word and letters.) | 1. *Aud.-mot.* (Slight vis. for "parallel.") |
| | 2. Mot. in throat and fingers. | 2. *Aud.-mot.*<br>2. *Vis.* |
| C. | 1. *Vis.,* mot. (?). | 1. *Vis.,* mot. (?). (Vis. more as wholes; do not show separate letters well.) |
| | 2. *Vis.,* mot. | 2. *Vis.,* mot. |
| G. | 1. *Vis., mot.,* aud. (slight). | 1. *Vis,* aud. for one. |
| | 2. *Vis., mot.* | 2. *Vis.* |
| Hs. | 1. *Mot,* aud. and vis. (lip-motor). | 1. *Lip-mot.,* aud. and vis. |
| | 2. *Mot.,* aud. and vis. (lip-motor). | 2. *Lip-mot.,* aud. and vis. |
| H. | 1. Voc.-mot. | 1. Mot. (tongue and palate), hand automatism. |
| | 2. Voc.-mot. | 2. Mot. (tongue and palate). |
| P. | 1. Vis., aud.-voc.-mot. | 1. Hand automatism. |
| | 2. Tendency to automatism. | 2. Hand automatism. |
| S. | 1. Vis. | 1. *Vis.* (artic. and hand-mot. when in difficulty). |
| | 2. Vis. | 2. *Vis.* (wrong start for some—vis., corrected visually). |
| Sun. | 1. *Vis.,* voc.-mot. | 1. *Vis.,* voc.-mot., *autom.* |
| | 2. *Vis.,* voc.-mot. (of letters). | 2. *Vis., hand-autom.,* 1 aud. (?). |
| T. | 1. *Voc.-mot., autom.* | 1. *Aud.* (of letters), voc.-mot. (?). |
| | 2. Autom. almost entirely. | 2. *Aud.* (of letters), especially prominent in "sigh," because of effort required to get rid of "Psy." |
| V. | (Omitted.) | |

* (1 and 2 indicate 1st and 2d lists.)

The table as a whole indicates that, for most subjects, there is not much difference in imagery control between oral and written spelling. A. represents the most marked case of shift here, using aud. for written spelling but not at all for oral. As to form of control in general, we find that A., C., G., Hs., P., S. and Sun. make some use of vis., while Ad., H. and T. apparently never use it. (One exception noted for Ad.)

(2) *Backwards.*

In order to study the spelling process under conditions such that the tendency to automatism would be lessened and the conscious control brought into prominence, we introduced the performance of spelling rather long words backwards. Little was heard of the dependence upon automatism in this series! Both oral and written spelling were tested, first with a preliminary list of ten words, then with a list of thirty, for which time records were kept by means of the stop-watch. The introspective accounts were valued for their own sake, but we were also on the lookout for any correlation which might exist between rate and accuracy of spelling, on the one hand, and type of imagery on the other. We shall discuss first the oral spelling, then the written, giving brief summaries of the introspections followed by the quantitative data.

### ORAL SPELLING.

### *Introspection of Subjects.*

### A.

Mostly *vis.* imagery.—Helped out at times by *mental pronouncing* of letters or of syllables, and occasionally by *aud.*

### Ad.

In general *spells* word forwards (aud.—voc.—mot.) to point which he needs. Some tendency to *pronounce syllables.* Slight *mot.* tendency in fingers. *No vis.* imagery, unless possibly in one case where hand-mot. tracing seemed to give it.

### C.

*Vis.* image of each word, but this gives rather general appearance of the word whole than separate letters. (*Cf.* report on normal spelling, p. 50.) To get these had to spell word forwards (*aud.-mot.*) and then go back. Slight tendency to *pronounce* word to fix the *vis.* image. Vis. images seemed to improve toward last. C. says she can always spell word more easily when she has *good vis. image.*

### G.

*Vis., aud. and artic.,* with *vis.* apparently predominant. Had clear vis. image of word forwards, though not of whole word at once ordinarily. Assurance seemed to come with this, though it was often necessary to *pronounce* (aud.mot.) the word or syllable to get the vis. image. Pronouncing appeared whenever "got up a stump."

Hs.

Did by syllables, by *spelling* word forwards. Used *vis., lip-mot.* and *aud.* of words and syllables. Chiefly *vis.* of letters in syllable. Main dependence on *vis.* and *lip-mot. Aud.* imagery slight. Pronounces syllable when gets stuck. Said at end of series: Only when I get all kinds of imagery to support one another that am successful. Only when I get definite *vis.* image as basis that do it easily. Can do without this, but am then very slow and almost invariably go wrong. Vis. image seems to take an effort and when lazy I fail to make this.

H.

First *spelled* whole word (in *mot.* terms) and so got the last letter. Then spelled to next to last letter, etc. Later got some syllables without reversing. *Can't get vis. image at all.* Occasionally helped by *hand-motor.*

P.

Had to repeat word and get *aud.* image. Often had to repeat again and divide into syllables. Then *visualized* on the window sill or on the power house, but letters kept disappearing. Usually had to pronounce whole word over again to tell what syllable I was working on. There was a little tendency to carry over normal forward-spelling habits, leading to difficulty.

S.

Predominantly *vis. Vis.* image of word, one syllable at a time, from which he read off backwards. Probably a certain amount of *articulatory,* but this not very noticeable.

Sun.

Whole process based on *vis.* image of word. When word was long it tended to disappear and I would have to *pronounce* it to bring it back. Found tendency to lose middle part entirely. The trouble is to hold the image fixed. Have to keep fixation as definitely as for actual vis. perception. There is always a black background. The letters are grey. As I pronounce each letter it fades away. As I get nearer the beginning both letters and background become brighter.

T.

Pronounced word as whole, then spelled in *aud.* and *artic.* terms. Tried to get letters by running back over sound of syllables. Where there was difficulty had to either spell out forwards or pronounce the syllable. Can't be sure whether I use *vis.* or just the *sound* of the syllable. Said at end, "Getting easier." Just *pronouncing* seems to give it. Think there was a little more *vis.* with the *sound* of the syllable, but *never fail to pronounce.* (Visualizing is in script.)

### V.

Spelled forwards (aud-voc-mot.), then backwards by syllables. *Pronounced* syllables to get bearings. *No visualizing.*

TABLE III. SPELLING BACKWARDS—ORAL.

| Word. | A. | Ad. | C. | G. | Hs. | H. | P. | S. | Sun. | T. | V. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. Complexity ... | r 7.6 | w 17.5 | w 17.4 | r 10.0 | w 17.6 | w 9.3 | r 12.0 | r 8.2 | r 6.5 | r 12.5 | r 16.5 |
| 2. Somnambulist. | w 12.4 | r 35.0 | r 74.5 | r 14.4 | w 23.4 | r 29.0 | r 23.6 | w 11.7 | w 31.4 | r 16.4 | r 17.5 |
| 3. Superstition .. | r 14.4 | r 32.0 | r 28.8 | r 18.2 | r 32.8 | w 19.4 | r 21.9 | r 7.8 | r 15.5 | r 20.6 | r 14.0 |
| 4. Generosity .... | r 14.1 | w 25.4 | r 18.0 | r 9.5 | r 17.4 | r 16.0 | r 31.4 | r 10.2 | r 10.0 | r 17.3 | w 12.0 |
| 5. Contemporary. | r 11.7 | r 30.5 | r 18.0 | w 18.4 | r 32.0 | w 24.7 | w 43.0 | r 12.4 | r 14.5 | w 49.0 | r 19.7 |
| 6. Requisite ..... | w 14.0 | w 11.4 | r 11.0 | r 6.0 | r 8.0 | w 12.8 | r 11.1 | r 5.4 | r 25.8 | r 15.3 | r 15.1 |
| 7. Municipal .... | r 10.2 | r 20.5 | r 13.5 | r 8.1 | r 31.7 | w 12.5 | r 13.3 | w 3.5 | w 7.2 | w 8.9 | r 14.2 |
| 8. Ignominy ..... | r 7.4 | r 19.3 | r 8.0 | r 7.0 | r 29.8 | r 15.7 | r 11.2 | w 4.4 | r 7.8 | r 11.3 | r 9.0 |
| 9. Fortuitous .... | r 9.0 | w 32.0 | r 12.6 | r 14.0 | r 23.2 | r 25.0 | r 16.2 | r 11.0 | w 18.0 | w 14.8 | w 17.5 |
| 10. Acquaintance . | w 16.5 | r 26.0 | w 15.5 | r 12.0 | r 26.4 | r 31.0 | w 28.2 | w 10.2 | r 15.8 | r 26.1 | r 33.0 |
| 11. Unexampled .. | r 8.0 | r 19.0 | r 20.0 | r 20.6 | r 21.0 | r 17.2 | r 20.0 | r 28.4 | r 10.0 | r 21.0 | r 16.1 |
| 12. Symmetrical .. | w 14.0 | r 21.0 | w 6.2 | r 9.5 | r 20.5 | r 22.8 | r 16.7 | r 7.4 | w 9.3 | r 70.0 | w 8.7 |
| 13. Reverberate .. | r 14.0 | r 26.8 | ? 22.7 | w 7.0 | r 30.7 | r 25.0 | r 24.5 | r 22.0 | r 22.5 | r 17.5 | r 13.0 |
| 14. Punctuation .. | w 11.0 | r 29.6 | r 18.0 | r 9.0 | r 26.5 | r 25.7 | w 12.9 | w 6.2 | r 10.0 | w 24.0 | w 15.5 |
| 15. Suitable ...... | r 7.0 | w 9.7 | r 11.8 | r 8.8 | r 10.4 | r 10.4 | w 19.0 | r 5.5 | r 11.0 | w 9.2 | r 10.4 |
| 16. Sociability .... | r 9.7 | r 22.0 | r 9.8 | w 15.4 | r 40.0 | w 47.0 | r 22.1 | r 9.2 | r 10.0 | w 13.0 | w 28.5 |
| 17. Magistrate .... | r 7.5 | w 20.0 | r 22.6 | r 10.0 | r 17.0 | r 19.0 | r 15.2 | r 8.0 | r 9.7 | r 13.2 | r 32.7 |
| 18. Fraction ...... | r 4.1 | r 20.5 | w 7.0 | r 4.2 | r 15.8 | r 9.6 | r 12.0 | r 5.0 | r 5.4 | r 11.5 | r 11.3 |
| 19. Daughter ..... | r 6.2 | r 12.8 | r 8.0 | r 7.0 | r 13.0 | r 9.7 | r 11.0 | r 10.8 | r 6.4 | r 11.7 | r 10.1 |
| 20. Technicality .. | w 11.4 | r 26.8 | r 14.8 | r 11.0 | r 64.2 | r 33.7 | r 18.2 | w 13.7 | r 12.3 | r 14.6 | w 13.5 |
| 21. Irresolute .... | r 9.6 | r 19.8 | r 11.7 | r 7.4 | r 23.2 | r 22.0 | r 18.7 | r 18.0 | r 12.7 | r 20.0 | r 20.5 |
| 22. Knowledge ... | r 15.2 | r 18.8 | w 14.0 | r 11.8 | w 15.6 | r 23.4 | w 24.5 | r 9.7 | r 7.7 | w 12.3 | r 23.0 |
| Average time ..... | 10.7 | 22.6 | 17.4 | 10.9 | 24.5 | 20.9 | 19.4 | 10.4 | 14.7 | 19.6 | 16.9 |
| Mean variation ... | 2.8 | 5.5 | 7.6 | 3.4 | 8.5 | 7.2 | 5.9 | 4.0 | 5.7 | 8.5 | 5.2 |
| Total errors ...... | 6 | 6 | 6 | 3 | 3 | 6 | 5 | 6 | 4 | 7 | 6 |

*Explanation of table:* Symbols for subjects are given on the top horizontal line; list of words used, in vertical column at left. In vertical column under each subject his results are given; accuracy indicated by r (right) or w (wrong); time for each word, by numbers representing seconds. Averages, totals, etc., are given at foot of table.

*Summary.* From these reports as a whole it is evident that this test calls forth a wide range of conscious controls, both of imagery and of the sensori-motor sort. All the subjects report some dependence upon pronouncing the word, and most report some spelling forwards. A., G., S. and P. are the only ones who do not have to resort to this latter clumsy method to any great degree, and P. seems to substitute for it repeated pronouncing of the word and of particular syllables. All but four of the subjects—Ad., H., T. (?) and V—report some *visual* imagery as an important factor, and even T. is inclined to think that vis. is present to a slight degree, especially toward the end of the series. C. and Hs. comment on the fact that they can do better when visual images are present in satisfactory form.

### *Quantitative Results Compared with Above Data.*

Our early results in the preliminary tests indicated that those who were able to use visual imagery were more rapid than those who could not and had to trust to more round-about means. We, therefore, tried to test this suggested correlation further by using a list of thirty rather decidedly difficult words. Unfortunately, however, we counted without our subjects in constructing this list, and, when we came to use it, discovered that it contained words which certain of them professed to be unable to spell forwards. When all such challenged words were excluded from the list, twenty-two remained. Table III represents the results obtained with these, both as to accuracy and as to time.

If we compare the accuracy of this spelling, as indicated by "Total Errors," we find the number of errors impartially distributed among the various types of subjects. Evidently, we cannot look there for correlation. The matter of the rate of spelling is rather more promising. If we arrange our subjects in order of speed, as given in the average time, we have the following list, beginning with the most rapid: S., A., G., Sun., V., C., P., T., H., Ad., Hs. This is evidently not in exact order of visualizing tendency, since V. comes before C. and P., and Hs. comes at the end of the list. At the same time the first four indicate that their major dependence is on the visual, though other aids do enter in, while all the rest find accessory devices more essential. Thus, both C. and Hs., who do their best work with good visual images, are also exceedingly dependent upon spelling the word or certain syllables. P. does less spelling, but makes an exaggerated use of pronouncing.

In general, we seem justified in saying that the results indicate that the rapidity of this form of spelling is favored by the ability to summon clear, vivid and stable visual images of the words without a very great need for accessory factors. A poor record, however, need not indicate an absence of visual verbal images, though it may be due to that. It may also indicate that the visual image will not stand alone, but needs other factors of the same character as those used by non-visual subjects, or that the visual image is not of a suitable character for this operation: *i. e.,* it may be of a word-whole in which the letters do not stand out clearly (*Cf.,* C.'s introspection), or it may constantly change form or disappear during the operation (*Cf.,* P. and Sun.), etc.

In other words, we cannot rely upon this as a purely objective test, since it would lead us into many errors of diagnosis. As a partially objective test, however, lending confirmation to the reports of the subjects, it would seem to be of greater value.

### WRITTEN SPELLING.

#### *Introspection of Subjects.*

For the majority of the subjects the imagery cues here were of the same type as in the preceding case (oral spelling). Where this was true we have not duplicated the reports. The following extracts, therefore, represent only the variations which appeared with the difference in procedure.

Ad.

Similar to preceding but easier.

C.

"I come to depend more and more on spelling each syllable (aud.-mot.) forward, and then doing it backward, partly from that, and partly from the vis. image accompanying forward spelling."

G.

"Took one syllable at a time and spelled to self first. This spelling gave vis. image of letters *in reversed order.* This vis. image was absolutely different from that in oral spelling, which was never reversed." From this point reports sometimes vis. of words straight ahead and sometimes of them reversed, as well as considerable aud.-artic. imagery. Some words "were spelled without watching the paper, as I found the vis. impression of the syllable already written a distracting thing."

Hs.

Like oral but easier. "Gain in ease seems to depend on greater facility in using both vis. and aud.-lip-mot.: *i. e.,* greater ease in holding a group of letters during time for writing them, once they have been gotten by spelling the word."

P.

"Similar to oral, but almost exclusive dependence on imaging separate *letters,* rather than *syllables,* as a unit on the paper (by spelling them in *aud.* terms) and copying down the letter. The same aud. method was worked at times with entire absence of vis."

S.

"Read off letters in order from vis. image. Closed eyes in order better to attend to vis. image and wrote rather automatically without looking." "Several articulations of the word with emphasis on syllables being written."

Sun.

"Great difficulty is to keep the vis. image fixed. The sight of the unusual appearance of the written part makes it almost impossible to keep the image. And then pronouncing the syllables brings the letters in the wrong places, which makes the word look still worse."

T.

Similar to oral except that she says, "Results were better when I kept eyes off paper."

V.

Like oral but harder because word looked so queer.

TABLE IV. SPELLING BACKWARDS—WRITTEN

| Word. | A. | Ad. | C. | G. | Hs. | H. | P. | S. | Sun. | T. | V. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. Sequestered .. | r 22.8 | r 25.8 | r 21.4 | r 31.0 | w 19.2 | r 47.0 | r 24.2 | r 14.1 | r 28.4 | w 24.1 | r 21.2 |
| 2. Simplicity .... | r 19.8 | r 17.4 | w 14.0 | r 24.3 | r 27.4 | r 20.8 | r 22.0 | r 14.0 | r 22.4 | w 25.8 | r 26.5 |
| 3. Assurance .... | r 20.2 | r 11.5 | r 10.0 | r 26.0 | r 17.0 | r 19.8 | r 25.8 | r 8.0 | r 38.4 | w 33.8 | r 22.0 |
| 4. Heterogeneous | r 26.4 | w 27.0 | r 30.3 | r 26.6 | r 32.4 | w 35.0 | r 33.1 | r 13.0 | r 32.0 | r 39.3 | w 32.0 |
| 5. Substitute .... | r 14.0 | r 21.0 | r 14.0 | r 20.4 | r 21.8 | r 25.0 | r 14.2 | r 10.5 | w 17.0 | r 66.2 | r 20.0 |
| 6. Friendliness .. | r 22.4 | r 30.0 | w 14.0 | w 16.7 | w 15.8 | w 16.0 | r 16.5 | r 16.7 | r 19.0 | r 22.5 | r 20.0 |
| 7. Equivalent .... | r 27.8 | r 15.0 | r 14.0 | r 17.8 | r 25.6 | w 25.0 | w 54.5 | r 8.7 | r 22.4 | w 19.0 | r 17.7 |
| 8. Credibility .... | r 22.0 | r 24.2 | r 12.8 | r 20.6 | r 32.0 | w 30.4 | r 21.1 | r 14.0 | r 21.8 | r 24.7 | r 21.3 |
| 9. Cylindrical ... | w 20.0 | r 24.2 | r 21.8 | r 20.0 | r 51.0 | w 26.7 | w 35.0 | w 11.5 | r 22.0 | r 24.6 | r 15.0 |
| 10. Vivacious .... | r 17.8 | r 16.6 | r 13.4 | r 21.0 | r 18.6 | r 12.5 | r 10.5 | r 10.8 | r 17.7 | r 15.8 | r 15.2 |
| 11. Utterance ..... | w 22.0 | r 10.3 | w 11.5 | r 15.8 | r 16.2 | r 18.2 | r 14.0 | w 13.6 | r 17.1 | w 21.0 | r 13.7 |
| 12. Temperament . | w 14.6 | w 26.8 | r 21.0 | r 14.0 | r 22.2 | r 26.0 | r 22.0 | r 12.2 | r 13.6 | w 13.0 | r 13.9 |
| 13. Reverence .... | r 14.0 | r 15.7 | r 13.6 | r 14.8 | r 13.7 | r 17.0 | r 16.6 | r 11.4 | r 15.4 | r 15.0 | w 12.2 |
| 14. Publicity ..... | r 11.8 | r 15.5 | r 12.5 | r 15.8 | r 18.8 | r 19.0 | r 13.3 | r 8.0 | r 16.3 | r 16.2 | r 14.0 |
| 15. Witchcraft ... | w 11.0 | r 15.8 | w 12.5 | r 18.0 | r 17.0 | w 15.0 | r 15.6 | r 16.2 | r 32.0 | r 19.0 | r 20.9 |
| 16. Tumultuous .. | w 24.4 | w 15.4 | r 9.3 | r 15.0 | r 27.2 | w 14.0 | r 31.4 | r 8.2 | w 35.0 | r 21.2 | r 21.5 |
| 17. Manuscript ... | r 21.0 | r 19.0 | r 13.0 | r 15.8 | r 20.2 | r 15.0 | r 13.7 | r 9.1 | r 22.2 | r 25.0 | r 20.0 |
| 18. Insatiable ..... | r 18.0 | r 21.0 | w 13.0 | r 23.2 | r 15.8 | w 17.0 | w 25.0 | r 11.2 | r 22.0 | r 33.0 | r 26.1 |
| 19. Chivalrous .... | r 21.0 | r 13.6 | w 8.0 | r 13.2 | w 27.0 | r 24.0 | w 17.8 | r 10.9 | r 17.7 | r 12.9 | r 21.8 |
| 20. Fictitious ..... | r 17.8 | r 17.8 | r 23.0 | r 12.6 | r 19.8 | w 35.0 | r 17.5 | r 11.2 | w 17.6 | w 21.0 | r 14.8 |
| 21. Intersperse ... | r 19.0 | r 15.3 | w 15.6 | r 14.8 | r 22.6 | r 20.0 | r 21.0 | r 16.0 | w 21.0 | r 16.0 | r 25.4 |
| 22. Promiscuous .. | r 17.0 | r 25.4 | r 11.5 | r 13.5 | w 20.0 | r 39.2 | w 36.7 | r 9.6 | r 19.8 | r 21.0 | w 20.3 |
| Average time ..... | 19.3 | 19.3 | 15.0 | 18.7 | 22.8 | 23.5 | 22.8 | 11.8 | 22.3 | 24.1 | 19.8 |
| Mean variation ... | 3.5 | 4.8 | 3.9 | 4.1 | 5.8 | 6.8 | 5.3 | 2.2 | 4.9 | 7.2 | 38. |
| Total errors ...... | 5 | 3 | 7 | 1 | 4 | 9 | 5 | 4 | 2 | 7 | 3 |

*Summary.* In general it is evident that this procedure is more difficult than the preceding, chiefly because the peculiar appearance is sufficiently disturbing to more than counteract any advantage that might be expected from the sight of the letters already written. Ad. and Hs., however, find this method easier, Ad. saying that the practice in reading backwards seems to help. S. did not find this method more difficult, but from the start he closed his eyes while writing, thus eliminating the factor of the strange appearance. G., Sun. and T. developed this method—of writing with eyes closed—for themselves and found it an advantage.

As to the kinds of imagery used, the subjects line up just as before, all reporting some *spelling* and *pronouncing,* and all but Ad., H., T. (?) and V. reporting some visual verbal, though certain differences in technique appear in connection with these images.

### *Quantitative Results.*

As in the list for oral spelling, our thirty words simmered down to twenty-two, owing to the orthographic limitations of our subjects. Table IV represents the results, as to accuracy and rate, obtained from these.

As in the case of the preceding results, accuracy in this form of spelling does not seem to be a function of any particular form of imagery, nor of the rate of spelling. Nor do we find here any convincing correlation between rate of spelling and the use of visual imagery, although the one subject who most obviously leads the procession is apparently the one who makes most satisfactory use of visual imagery. The lack of such a correlation can hardly surprise us here when we note the large number of other factors which enter in to obscure this issue. (Note especially the desperate tone of Sun.'s introspection.)

## C. PRONOUNCING.

### (1) *Letters Given in Normal Order.*

A short series, consisting of five words, polysyllables familiar to the subjects, was given to the subject orally, letter by letter. On completion of the spelling the subject was to give the word.

The task was thus simple enough to constitute no real problem, but it did furnish another opportunity of observing the imagery form in which the word might appear to the various subjects. We called for introspection, both on the appearance of the letters as they were heard, and on the form taken by the word as it was recognized. The tendency to automatism: *i. e.,* to an immediate vocal response—was somewhat inhibited by the fact that the subject usually recognized the word before the spelling was finished and had to wait for the completion of this. Often an incorrect word was taken tentatively (*e. g.,* for "hypothesis," "hypotenuse," "hypocrite," etc., might appear), and then rejected as the spelling progressed, which gave us a chance to observe the form of verbal imagery.

The following table gives the introspective observations:

TABLE V.

| *Subj.* | *Introspection.* |
|---|---|
| A. | *Vis.* (letters), *aud.* (word). Letters visualized as far apart. |
| Ad. | *Aud.-voc.-mot.* |
| C. | *Vis.* Word flashes up. Many tentative guesses. |
| G. | *Vis.* (letters and word), *mot.* (word). Letters at first far apart. Move together when word is pronounced. |
| Hs. | *Lip-mot.* |
| H. | *Mot.* (indistinct vis. for one (?)). |
| P. | *Vis.* (some letters), *aud.* (word). |
| S. | *Vis.* (letters and word), *mot.* (word)—after vis. verbal. |
| Sun. | *Vis.* (letters and word), *mot.* (syllable and word). Letters appeared far apart, but moved together when pronounced. |
| T. | *Mot.* (letters and word), vis. for one (?). |
| V. | (Omitted.) |

Various methods are evident from the above table. Some form of auditory or motor appears in every case but one (C.). In several cases visual images of the individual letters appear as they are given, followed by either visual or auditory or vocal-motor of the word, or a combination of all these. A., C., G., P., S., Sun. and T. (?) report such visual of certain letters; C., G., H. (?), S. and Sun. report more or less visual verbal; Ad., Hs., H. (?) and T. (?) report no visual of either sort. Three subjects (A., G. and Sun.) note a tendency to visualize the letters as widely separated, due apparently to the fact that they are pronounced slowly. With G. and Sun. they seemed to move together as the word was pronounced.

(2) *Letters Given in Reversed Order.*

As in the case of the spelling, it was found that a variation sufficient to introduce a real problem into the task of recognizing the word greatly increased the dependence upon conscious controls of the imagery sort and lessened the tendency toward automatism. Spelling the word backwards, orally, for the subject to pronounce proved an effective device from this point of view. After a short preliminary set, two series of thirty words each were given: (1) Where the letters were given one per second; (2) where they were given two per second. The technique was as follows: The experimenter started the stop-watch as she began the word and regulated the rate of spelling by observation of the watch (with the aid, also, of the habit acquired by preliminary practice). After completion of the spelling the watch was allowed to run until the word was pronounced by the subject. The time between the speaking of the last letter by the experimenter and the pronouncing of the word by the subject was recorded and kept for comparison with the introspective data. If the word was not recognized on the first spelling it was repeated as many times as necessary.

SUMMARY OF INTROSPECTIVE INDICATIONS.[9] The records show a dependence upon a wide range of imagery cues, varying both with the subjects and with the rate of giving the letters. All subjects report, as usual, when in difficulty with a word, some form of the auditory-vocal-motor combination. The following subjects mention the use of visual imagery in greater or less degree: For 1, A., C., G., Hs., P., S., Sun.; for 2, A. (slight amount), C., S., G., Hs., P. and Sun. (The last four report it as less than for rate 1.) Ad., H., T. and V. report no visual.

Other differences, apparently as important as those in imagery *type,* appear in the technique of the different subjects. Thus, the difference in control over visual images shown by S. and C. is marked, the former arranging his so satisfactorily and systematically that he sometimes had the word even before the experimenter had finished reading the letters, while the latter complained constantly of the fact that the letters were in a confused mass before her. For the subjects who made little or no use of visual imagery, equally significant differences in technique are evident, if we compare H. and P., on one hand, with T., on the other. The desperate attempts of the former two to acquire a satisfactory method, and the confusion resulting from the attempt to retain more than they were able were sharply contrasted with the simple method of the latter of attending merely to the first and last parts of the word and guessing the rest from these. V. is distinguished from most of the others by the degree of stability of the original series in auditory-motor terms, as shown by the fact that she can return to this again and again, in spite of her various attempts to manipulate the letters in other ways. From the standpoint of finally winning out on her words she would seem to have an advantage in her technique over such a subject as C., though we might expect the latter to be more rapid than the former for the words which she gets.

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[9] For more detailed statements taken from the introspections see Appendix 155.

Another point worthy of note is the sharp change in technique reported by most subjects for the different rates of presentation. All but S. found the faster rate much harder, and most reported a different mode of approach to the problem. In general, the amount of visual imagery seemed to be diminished, and with this change the efficiency of the performance decreased.

RELATION BETWEEN QUANTITATIVE RESULTS AND INTROSPECTIONS. We have attempted to discover whether any correlation exists between use of visual imagery and excellence in these tests, from two points of view: both with regard to the number of words which the subject was able to get on one spelling and with regard to the promptness with which he was able to say the word. The calculation of the latter factor was complicated by the number of failures to get the word on one spelling and the fact that these fell on so many different words for the different subjects. Thus, out of our list of thirty words, in 1 there were only six which all the subjects recognized on one spelling, while for 2 there was only one. The question arises, therefore, whether there is anything which can be taken as a significant average.

There is certainly nothing which can be considered as of very high statistical value under these conditions. We have, however, calculated two sets of averages which seemed suggestive. The first of these are the averages for each subject of the time records for all the words which he was able to pronounce with one spelling: For the second we have taken as a basis for calculation the smallest number of words that *any* subject got with one spelling, and have averaged that same number of cases for every subject, taking always the lowest time records on his list. These calculations appear in Table VI.

### TABLE VI.

#### RATE I.

*(1) No. of Words Pronounced After 1, 2 or 3 Spellings.*

| No. of Spellings. | A. | Ad. | C. | G. | Hs. | H. | P. | S. | Sun. | T. | V. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 .............. | 26 | 29 | 24[1] | 29 | 23[1] | 20 | 17 | 27 | 27 | 25 | 25 |
| 2 .............. | 3 | 1 | 3 | 1 | 4 | 8 | 10 | 3 | 2 | 5 | 4 |
| 3 or more...... | 1 | 0 | 2 | 0 | 2 | 2 | 3 | 0 | 1 | 0 | 1 |

List of subjects according to number of words pronounced with 1 spelling: Ad. and G., S. and Sun., A., T. and V., C. (?), Hs., H., P.

*(2) Average Length of Interval Before Pronouncing.*

*(a) Averages for All Words Pronounced by Each Subject with 1 Spelling:*

| Subject ........ | A. | Ad. | C. | G. | Hs. | H. | P. | S. | Sun. | T. | V. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Time in sec..... | 2.8 | 3.0 | 1.8 | 1.4 | 4.8 | 3.9 | 13.2 | 1.3 | 2.2 | 2.5 | 20.9 |

List of subjects in order of rapidity: S., G., C., Sun., T., A., Ad., H., Hs., P., V.

*(b) Averages for Lowest 17 Records in Each List.*

| Subject ........ | A. | Ad. | C. | G. | Hs. | H. | P. | S. | Sun. | T. | V. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Time in sec..... | 0.8 | 1.3 | 1.2 | 0.76 | 2.2 | 3.1 | 13.2 | 0.9 | 1.4 | 1.3 | 4.5 |

List of subjects in order of rapidity: G., A., S., C., Ad., T., Sun., Hs., H., V., P.

#### RATE II.

*(1) Number of Words Pronounced After 1, 2 or 3 Spellings.*

| No. of Spellings. | A. | Ad. | C. | G. | Hs. | H. | P. | S. | Sun. | T. | V. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 .............. | 25 | 21 | 17 | 27 | 14 | 17 | 12 | 24 | 17 | 19 | 24 |
| 2 .............. | 4 | 5 | 8 | 3 | 10 | 8 | 17 | 6 | 9 | 8 | 5 |
| 3 or more....... | 1 | 4 | 5 | 0 | 6 | 5 | 1 | 0 | 4 | 3 | 1 |

List of subjects according to number of words pronounced with 1 spelling: G., A., S. and V., Ad., T., C. and H. and Sun., Hs., P.

[1] One word omitted.

*(2) Average Length of Interval Before Pronouncing*

*(a) Averages for All Words Pronounced by Each Subject with 1 Spelling.*

| Subject ........ | A. | Ad. | C. | G. | Hs. | H. | P. | S. | Sun. | T. | V. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Time in sec..... | 4.0 | 6.5 | 7.1 | 2.8 | 8.7 | 10.7 | 18.8 | 2.7 | 4.1 | 3.9 | 28.5 |

List of subjects in order of rapidity: S., G., T., A., Sun., Ad., C., Hs., H., P., V.

*(b) Averages for the 12 Lowest Records in Each List.*

| Subject ........ | A. | Ad. | C. | G. | Hs. | H. | P. | S. | Sun. | T. | V. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Time in sec..... | 1.5 | 2.4 | 4.4 | 1.4 | 5.4 | 7.7 | 18.8 | 1.8 | 2.0 | 2.3 | 14.9 |

List of subjects in order of rapidity: G., A., S., Sun., T., Ad., C., Hs., H., V., P.

It is evident by inspection of the above data that they do not furnish a short and easy road toward the interpretation of the imagery used. To attempt to make a diagnosis on the basis of the quantitative material alone would involve us in endless difficulties, if we test the accuracy of such a diagnosis by a comparison with the introspection. Yet in spite of this lack of absolute objective significance, the results show an interesting connection with the introspective accounts, which should not be overlooked. We may bring out this point by reference to the above results.

If we arrange the subjects according to the excellence as indicated by the number of words pronounced with one spelling, we have the following order:

1.—Ad. and G., S. and Sun., A., T. and V., C., Hs., H., P.
2.—G., A., S. and V., Ad., T., C. and H. and Sun., Hs., P.

If we make a division here at the end of the first five, in 1 four of the first five use visual images to a marked degree, while three of the last six use no visual and the other three report difficulty in controlling what they have. Yet the dividing line certainly cannot be thought a sharp one when we note that the difference between A. and the next lower is only that of one word. In 2, of the first five, three are strongly visual but two are non-visual, while of the lower six, four use some visual and only two do not. Here there is a greater lack of correlation. It seems to be true that, whatever may be the influence of a particular sort of imagery, the effect of clumsiness of technique may serve to obscure this. From this point of view it is interesting to note that P. is at the end of the list by a good margin in both cases.

A comparison of the *rates* seems to give somewhat more correlation. The following gives the order of the subjects for each rate and for each method of calculating the average.

1. (a)—S., G., C., Sun., T., A., Ad., H., Hs., P., V.
   (b)—G., A., S., C., Ad., T., Sun., Hs., H., V., P.
2. (a)—S., G., T., A., Sun., Ad., C., Hs., H., P., V.
   (b)—G., A., S., Sun., T., Ad., C., Hs., H., V., P.

The most obvious fact about these lists is that the four lowest are constant throughout. Two of these—H. and V.—report no visual, while the other two are unable to rely upon this form predominantly. (Still one of the latter—Hs.—appears as a good visualizer in most of our tests.) On the other hand, the first four, with one exception—T. in list 2 (a)—all report considerable use of visual imagery. The intermediate three represent certain anomalous cases.

In general, then, we may say that the quantitative expression of these results has confirmatory value to the extent that a very high degree of excellence would lead us to look sharply, and expectantly, for the presence of good visual imagery, while a low degree would prepare us for its absence. Indeed, a failure to find this would lead us to look for some "good excuse" in the subject's introspection; such, for example, as that furnished by T. in her account of skillful guessing which seems like a fairly good substitute for the visual image, or by P. in his description of the inadequacy of the visual image and his need of other aids, and by Hs. in his emphasis upon the primary significance of the aud.-lip-motor factors.

### d. MEMORY TESTS.

None of the tests under this heading are "memory tests" in the sense that they are designed as, primarily, investigations *of* memory, but rather because they are attempts to study imagery by means of an appeal to memory. Like the tests in reading, these present a much more heterogeneous assemblage of materials than do those of spelling and pronouncing. In the first place we have varied our materials considerably, so that we might appeal, as far as the stimulus was concerned, to the various sensory fields, and, in the second place, when material of one sort was presented perceptually there was always the possibility of an ideational translation into some other form. Thus, we have to be on the lookout, both for the memory image proper—*e. g.,* a visual image for a color, a kinæsthetic image for a movement, etc.—and for various possible representative images—*e. g.,* verbal for any sort of material, visual for a movement, etc. Thus, we have the same sort of complexity of report required as in the case of the reading of descriptive passages. A large share of our tests were planned to appeal directly to verbal imagery of some sort, if we include in this imagery for letters and for numbers. In addition to these we attempted to appeal to the non-verbal imagery through (1) series of disconnected colors and forms, (2) pictures, both colored and uncolored, and (3) drawing. (This covers simply what we have termed the preliminary tests. Others were added later). In all these cases we were first interested in securing introspective data as to the imagery used by the various subjects under the different conditions imposed in these experiments, but, in the second place, we have watched for any correlations between the objective results and the above data.

### (1) *Letters and Numbers—Given in no Special Arrangement.*

Both oral and visual presentation were used. In the former the letters were read to the subject, as unrhythmically as possible, at a rate of about two letters in three seconds. In the latter the letters (in typewritten form) were exposed to the subject through a slit and he was directed to read them once. Neither procedure, evidently, is strictly accurate and we have, accordingly, not attempted a comparison of the objective results. In the case of visual exposure especially there was a wide difference between the subjects in the time that they took for their "one reading." In both cases the subject was to write the terms which he remembered, and give his introspection on the process of learning and of reproducing.

For each kind of presentation two series were used—one of six terms and one of nine. Each series had four groups, each consisting of three groups of letters. The first of these groups consisted of sets of consonants, so arranged as to avoid, as far as the experimenter could judge, common associative connections. The second consisted simply of numbers. The third and fourth were letters again, but with vowels included. In the third these were arranged so as to give a simple combination of nonsense syllables, but nothing was said to the subject of this fact. They were given to him as another group of letters, in the attempt to see whether he would notice the possible syllable grouping and whether this would alter his method of learning; as, for example, by the introduction of the *pronunciation* of the syllables. In the fourth the letters were so arranged that the pronunciation would be more difficult and would give a less satisfactory cue to the individual letters.[10]

Table VII indicates in brief the imagery reported by the various subjects. The usual abbreviations are employed and the forms which were most prominent are italicised. Where the subject indicated that the pronouncing of a *syllable* entered in, we have represented this thus—(syl.).

TABLE VII.

*Reports of Subjects.*

| Test. | A. | | Ad. | C. | |
|---|---|---|---|---|---|
| | *Oral.* | *Written.* | *Or. and Written.* | *Oral.* | *Written.* |
| 6-letter | | | | | |
| (1) | Aud.-voc. | *Aud.-voc.,* vis.? | Aud.-voc. | *Aud.*-mot. | *Aud.-mot.,* vis. |
| (2) | “ “ | “ “ | “ “ | “ “ vis. | “ “ “ |
| (3) | “ “ | “ “ (syl.) | “ “ | “ “ “ (syl.) | “ “ vis. (syl.) |
| (4) | “ “ | “ “ vis. | “ “ | “ “ “ “ * | “ “ “ “ |
| 9-letter | | | | | |
| (1) | *Aud.-voc.,* vis. | *Aud.-voc., vis.* | “ “ | “ “ “ | “ “ “ |
| (2) | “ “ | “ “ “ | “ “ | “ “ “ | “ “ “ |
| (3) | “ “ “ (syl.) | “ “ “ (syl.) | “ “ (syl.) | “ “ “ (syl.) | “ “ “ (syl.) |
| (4) | “ “ “ | “ “ “ “ | “ “ | “ “ “ “ * | “ “ “ “ |

* Pron'd one good syl. instead of whole thing.

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[10] The following are groups 3 and 4, as given visually:

| *6-Letter Series.* | | *9-Letter Series.* | |
|---|---|---|---|
| 3 | 4 | 3 | 4 |
| nadwom | owckie | latzebwyr | dutczyrhk |
| larbos | tczohl | terganfor | ghasczteg |
| tylfis | yetsch | kivmolrut | tschyjhni |

The groups given orally were:

| | | | |
|---|---|---|---|
| qervak | cklagh | zagrenhut | pschitzyl |
| romlin | szkohn | lemjibroy | sawljuyck |
| walset | jsardt | tokwyslat | hrdlahzka |

| | G. | | Hs. | | H. | |
|---|---|---|---|---|---|---|
| 6-letter | *Oral.* | *Written.* | *Oral.* | *Written.* | *Oral.* | *Written.* |
| (1) | Aud. | *Aud.*-mot., vis. | Aud.-*Lip-mot.* | *Lip-mot., vis.* | Art. (aud.) | Art. (vis.) |
| (2) | Aud., vis.* | “ “ | “ “ | “ “ | | |
| (3) | “ “ | “ “ “(syl.) | “ “ “ (vis.) (syl.) | “ aud. “ (syl.) | Omitted. | |
| (4) | “ “ | “ “ “ “ | “ “ “ vis. | “ “ “ “ | | |
| 9-letter | | | | | | |
| (1) | “ “ | “ “ (“?) | “ “ “ | “ “ “ | *Art.* aud. | Art. |
| (2) | “ “ | “ “ vis. | “ “ “ | “ “ “ | “ “ | “ |
| (3) | “ “(syl.) | “ “ “(syl.) | “ “ (syl.) | “ (syl.) | “ * | “ (aud.?) |
| (4) | “ “ | “ “ “ “ | “ “ “ ( “-hard) | “ “ “ | (omitted) | (syl.) |

* Aud. for one part, and vis. for another.

* Syllable distracted attention.

| | P. | | S. | | Sun. | |
|---|---|---|---|---|---|---|
| 6-letter | *Oral.* | *Written.* | *Oral.* | *Written.* | *Oral.* | *Written.* |
| (1) | Aud. | *Aud.*-art. (vis.) | Vis., art. | Vis., art. | *Vis.*-art. | *Vis.*, art. |
| (2) | “ | “ “ | *Vis.*, art. | *Vis.*, art. | “ “ | “ (“) |
| (3) | “ (syl.) | “ (syl.) | Vis., *art.* (syl.) | Art. (syl.) | “ (“) (syl.) | “ “ |
| (4) | “ “ | “ vis. “ | “ “ “ | *Vis.*, art. | “ “ | “ (“) |
| 9-letter | | | | | | |
| (1) | “ | “ (art.) | Art. | *Art.*, vis.? | *Vis.* (aud.?) | “ “ |
| (2) | “ (art.) | “ “ | *Art.*, vis. | “ “ § | “ art. (“) | “ “ |
| (3) | “ (syl.) | “ (syl.) | Art., *vis.* | “ “ | “ “ (“) (syl.) | “ “ (syl.) |
| (4) | “ “ * | “ “ * | “ “ | Art., *vis.* | “ “ | “ “ |

* Made syl. of part only.—*Cf.* C.

§ Vis. images too profuse to be depended on.

| | T. | | V. | |
|---|---|---|---|---|
| 6-letter | *Oral.* | *Written.* | *Oral.* | *Written.* |
| (1) | Aud.-voc. | Aud.-voc. | Aud. (1 vis.) | Aud.-voc. |
| (2) | “ “ | “ “ | “ | “ “ |
| (3) | “ “ (syl.) | “ “ (vis.?) (syl.) | “ (hand-mot.) | “ “ (syl.) (vis.) |
| (4) | “ “ | “ “ “ | “ -voc. | “ “ “ “ |
| 9-letter | | | | |
| (1) | “ “ | “ “ | “ | “ |
| (2) | “ “ | “ “ | “ | “ |
| (3) | “ “ (syl.) | “ “ “ | “ -voc. | “ “ “ |
| (4) | “ “ | “ “ “ | “ “ | “ “ |

*Summary.* By this table we see that all subjects reported some form of aud., voc.-mot. or aud.-voc.-mot. imagery. Ad., H., T. and V. reported no vis. with this (except for occasional, sporadic cases mentioned by the last three). P. used no vis. with the oral procedure and only a very slight amount with the visual exposure. In general, there seems to be a greater tendency to introduce vis. for the visual mode of presentation—that is, in the process of recall. See, for example, A., C., Hs., as well as P., H. and T., who never observed it with the other procedure. Similarly, P., T. and V. noted a considerable tendency to hear the letters in the experimenter's voice, with the oral procedure, but not with the other. H., S. and Sun. report an entire or almost entire lack of aud. imagery. All the subjects but S. found a tendency to get the letters as *syllables* in some of the cases where this was possible, although for the fourth group several commented on the difficulty of pronouncing, or fell back more on vis. imagery. Three of the subjects—C., S. and Sun.—commented on the fact that, in certain cases at least, their feeling of assurance came only with the artic. formulation, that they did not feel that they could rely on the vis. In some cases, however, C. felt that the vis. would be sufficient if she lost the other. Sun. showed a growing tendency to attribute importance to the artic. factor. In the early part of the series she said: "The pronouncing seemed to have no value in remembering the form, perhaps gave conviction that written form was correct," while toward the end she said: "The artic. image gives the cue for the reinstatement of the vis. image. The artic. image may be very slight, but if it is not present, there is simply a blank. In trying to remember, in order to fixate the vis. image I begin to pronounce as soon as I see the figures or letters." Another indication that the articulation was quite readily stimulated came in connection with one of the sets of difficult combinations of letters, where she said: "Disgusted with form of image. Letters do not look right thus combined. Motor sensation of gritting teeth at last group (rdt.). Vis. image stood out very distinctly, but some pronouncing attempted—very slight."

In general this test has seemed well worth while for the diagnosis of differences in imagery normally used in attacking such a problem as we offered here. It has seemed especially satisfactory in calling to the attention of the subject the degree to which the auditory-vocal-motor complex is used. We should not be willing, however, to rely on it as the sole indication of the capacity of the subject to used *visual* imagery, since we seem to have in this test one which has a greater stimulating power for other forms than for the visual. Thus, the use made of visual imagery by even A., C., S. and G. is relatively much less than in the tests already reported on spelling backwards and pronouncing from words spelled backwards. It is here given a secondary position much more frequently. A search of these tables for a real "visualizer" would yield most unsatisfactory results, if we mean by that one who uses no other form.

### (2) *Materials Given Visually in Spatial Forms.* (Binet's letter squares.)

A card was shown, divided into nine spaces—1 in. x 1½ in.—each space containing one letter, number or other term. For the first series the subject was allowed to read them through twice at a natural rate, while for the second he was given a fixed time, constant for all the subjects. In each case he was to reproduce the terms on a blank card divided into similar spaces. For the first series, nine cards were used, as follows: 1, Letters; 2, Numbers; 3, Punctuation marks and other symbols; 4, Combination of 1, 2 and 3; 5, Monosyllabic words (nouns); 6, Monosyllabic words (verbs); 7, Geometrical figures (circle, triangle, etc.); 8 and 9, Colored papers. In 7, the reproduction consisted in a rough drawing of the figure; in 8, the subject was given strips of the same colors to arrange in the order given, while in 9 he was simply to write the names of the colors.

Series II consisted of seven cards as follows: 1 and 2, Letters; 3, Monosyllabic words; 4, Circles crossed by lines in various arrangements; 5, Flags of various sorts; 6, Colored geometrical forms; 7, Flags marked with colors—only four colors used (red, blue, yellow and black), but these repeated in different forms on the different flags.

As usual we were first interested in seeing what differences appeared with the different subjects, as described in their introspections. We also attempted to discover whether any correlation existed between the accuracy of the results with the various kinds of materials and the nature of the imagery used, sufficient to justify us in using these as objective tests. It was for the latter reason that we used the two methods of procedure, in the one case securing equality of number of readings and, in the other, equality in time for reading. The results proved, however, so completely lacking in parallelism with the introspections that we have not attempted to present the objective data. We shall, therefore, use this test simply for its introspective value.

Table VIII presents the introspective data obtained from this test. For convenience of comparison we have broken into our division into series (I and II), in order to put together the observations on letters, on words and on "concrete" materials.

TABLE VIII.

*Introspective Observations of Subjects.*

| Test. | A. | Ad. | C. | G. |
|---|---|---|---|---|
| I. 1 and 2. | Aud.-voc. | *Aud.-voc.* | *Aud.-voc.,* vis. | *Vis.* (aud.-voc.), *assoc.* |
| II. 1 and 2. | “ “ | “ “ | “ “ “ | “ “ “ “ |
| I. 5 and 6. | *Aud.-voc.,* vis. | “ “ (assoc.) | “ “ “ | “ (aud. ?) “ |
| II. 3. | “ “ “ | “ “ | “ “ “ | “ “ |
| I. 3 and 4. | *Vis.,* voc. | “ “ (eye or hand-mot.) | *Aud.-voc., vis.* | “ (aud. and mot.)“ |
| I. 7. | *Vis.* | “ “ | Aud.-voc., *vis.* | Vis., aud.-mot. |
| II. 4. | “ | “ “ | *Vis.* (aud.) | ? “ “ “ |
| II. 5. | “ (assoc.) | “ “ (eye-mot.) | “ | Vis., “ “ “ |
| I. 8. | *Vis.,* aud.-voc. | “ “ | *Aud.-voc.,* vis. | Vis., aud.-voc. |
| I. 9. | *Vis., aud.-voc.* | “ “ | “ “ “ | “ “ |
| II. 6. | “ (aud.-voc.) | “ “ | *Vis.* (aud.) | *Vis.* |
| II. 7. | “ “ “ | “ “ (“ “ ?) | “ “ | “ |

|  | Hs. | H. | P. | S. |  |
|---|---|---|---|---|---|
| I. 1 and 2. | *Lip.-mot.,* vis. | *Artic.* (aud.?) | *Aud.-voc.* (assoc.) | *Vis., artic.* | Vis. very profuse, but main dependence for accuracy on artic. |
| II. 1 and 2. | *Aud.-lip.-mot.,* vis. | “ (rhythm) | *Aud.,* vis. “ | *Vis.* |  |
| I. 5 and 6. | *Lip.-mot., vis.* | “ (rhythm) | *Aud.* | “ “ |  |
| II. 3. | Aud. “ “ | “ (vis.) | *Aud.,* vis. | “ “ |  |
| I. 3 and 4. | *Vis.,* lip.-mot. | Artic. (1 vis.) | Aud., *vis.* |  |  |
| I. 7. | *Vis.* | “ (hand-mot., vis.) | *Vis.* | *Vis.* (artic.?) |  |
| II. 4. | *Vis.* (hand-mot.) | “ “ “ “ | ? | “ (assoc.) |  |
| II. 5. | “ “ “ | “ “ “ “ | ? | “ |  |
| I. 8. | *Vis.,* lip.-mot. | “ vis. | *Aud., vis.* | “ artic. |  |
| I. 9. | “ “ (assoc.) | “ | “ “ | “ “ |  |
| II. 6. | *Vis.,* aud.-lip.-mot. | “ “ | *Vis.* | “ “ |  |
| II. 7. | “ “ “ “ | “ “ (hand-mot.) | *Vis.,* aud. | “ |  |

|  | Sun. | T. | V. |
|---|---|---|---|
| I. 1 and 2. | *Artic.,* vis. | Aud.-artic. | Aud.-voc.-mot. |
| II. 1 and 2. | “ “ (made syls.) | “ “ (assoc.) | “ “ “ |
| I. 5 and 6. | “ “ (rhythm) | “ “ | “ “ “ |
| II. 3. | “ “ (vague) | “ “ | “ “ “ |
| I. 3 and 4. | “ “ (assoc.) | “ “ (vis.) | “ “ “ |
| I. 7. | *Vis.* (artic.) | *Vis.* (aud.-artic.) | “ “ “ (vis.) |
| II. 4. | “ | “ | “ “ “ “ |
| II. 5. | “ | “ | “ “ “ “ |
| I. 8. | “ *artic.* | “ artic. | “ “ “ |
| I. 9. | “ “ | *Artic.,* vis. | “ “ “ “ |
| II. 6 and 7. | “ “ | Vis., aud.-artic. | “ “ “ “ |

*Summary.* The reports on the letter, number and word groups may be passed without comment, since they represent about the same variations as were indicated in the preceding series. In the groups of symbols, forms, colors and combinations of forms and colors, however, we have distinctly new material. Here we must note first that these may be learned either by a memory image, which must be *visual,* or by a *name,* a *verbal image,* which might be of any sort, but which as a fact seems to belong to some part of the *auditory-vocal-motor* com plex always—or even by eye- or hand-motor processes. For these materials, therefore, where we have indicated "visual," it signifies a visual memory image—a "concrete," non-verbal image—but where we have indicated "auditory" or "lip-motor," etc., it always means some form of verbal imagery. In these tests as a whole we find a considerable tendency for visual memory images to appear, at least in a vague form. In fact, Ad. is the only subject who fails entirely to report it, though H. and V. report very little and very unsatisfactory visual imagery. P. reports a fair amount of it but describes it as indefinite and lacking in detail. S. has an abundance of visual imagery, perhaps more than any of the other subjects, but finds this very profusion a disadvantage, since any number of additional terms may appear in the given space, and he then needs the articulatory to decide which belongs there. In general, A., G., Hs., S. and Sun. seem to use the most visual imagery here, C., P. and T. use a fair amount, while Ad., H. and V. use a minimum or none at all.

We should note, before leaving these tests, that we have not said, by any means, all that is important with reference to memorizing when we have described the imagery used. Another highly significant factor is the development and use of associations. The majority of the subjects notice these and use them to advantage when they are present in an obvious way, but the subject who made by far the best record for the series—G.—was noteworthy for the quickness and ease with which she manipulated her materials to adapt them to some such associative connection, often one of a very dramatic character.

### (3) *Letters Given Visually and Reproduced in a Different Order.*

(See description, p. 26.)

As indicated in the above description, these tests were given primarily to see whether we could find in them satisfactory objective tests, as many writers would lead us to expect. The two methods of presentation were used in order to lessen the differences which might arise between the slow and the rapid readers. The method of indicating the order in which the series was to be written was chosen in order that no verbal distraction might be introduced between the reading and the writing of the letters. Introspection was taken in every case, since it is only by comparison with this that we can evaluate the tests as objective or not. We have looked for a correlation both in the rapidity and in the accuracy of the reproduction, since it seemed that a "visualizer" might have the advantage in both these respects. Only six subjects were used, including three whom we had found in other tests to be ready visualizers—C., Hs. and S., and three who were relatively lacking in this capacity—H., P. and T. (H. was omitted in Series II.) This would not be, evidently, a sufficiently large number of subjects to demonstrate in a positive way the objective value of these tests, but a lack of correlation with these subjects serves to cast doubt on the possibility of using this test where it cannot be checked up by introspection.

On the following pages we present the data which we have gathered here. The summary of the introspections furnishes one set of facts which must be known for such a correlation. It is evident from this at once that we have no subject who depends, for this performance, to any exclusive degree on visual imagery, although we have three of the most visual subjects that we have been able to secure. Moreover, we have no subject who has such satisfactory and complete visual imagery that he can see the whole set of letters at once and simply read them off backwards. For all of our subjects the visual imagery seemed to be the same sort of serial thing as the auditory and the articulatory. That persons exist who have visual imagery which they can use in the other way, we have no reason to doubt, but we seem justified in asserting that many persons who deserve the title of "good visualizers" have not such a control over their visual images. In so far as this is true the advantage claimed for the visualizer in this test would apparently dwindle in its importance.

Another factor which would seem to obscure the effects of the particular sort of imagery used is the utilization of associations in different degrees. For many of the subjects the presence or absence of such associations seems the most significant factor in the learning and the most effective in producing success or failure.

In spite of these drawbacks to this method, which are suggested by a consideration of the introspection alone, we have attempted to determine by reference to the objective results whether any advantage does exist in favor of the better visualizers. Of the subjects here used, C., Hs. and S. seemed to make the best and most frequent use of visual imagery, though none of them mention it as their main resource and none of the others report it as entirely absent. Of the other three, P. apparently relied upon visual imagery more than did the other two. The following brief summary of the introspections indicates the main differences in method.

C.

Aud.-mot. strongest and most persistent form. Had to go through the whole series each time. As I reproduced I had vis. images, also head-movements as for reading. Frequent associations. Sometimes when I lost the aud. I filled out from the vis., but had less confidence in this.

Hs.

Aud.-lip-mot. and vis. When former is unsatisfactory the vis. is not sufficient to do the work. Had to repeat the whole series to get each letter. (Could actually be heard whispering them over.) Relatively few associations.

H.

Artic. decidedly the main cue, though occasional aud. and vis. were reported. Whole series had to be articulated for each word. (Actual semi-audible articulation with marked rhythm.) Fairly frequent associations.

P.

Aud.-vis. in varying degrees for letters. Have to run through each line each time. Great dependence on associations. Vis. as usual vague.

S.

Artic.-vis. in varying degrees. Abundant associations. Had to go through each line each time. Vis. sometimes too profuse and thus confusing.

T.

Pronouncing (aud.-mot.) and some vis. (quite slight). Had to go through each line to get given letter. Associations in almost every series.

The following table represents our numerical data. First, we offer the materials with regard to *time* required for reproduction. Here, however, we are puzzled to know how to treat the material which we have secured. Shall we simply take the averages for the changed order of reproduction and assume that the lowest of these represent visual tendencies, while the highest represent lack of these, or shall we say that the visualizer will show least disturbance relative to his rate for normal reproduction? With our data it makes a considerable difference which method we pursue. We find, for example, in both series that C. has the lowest absolute time record for the changed order of reproduction, but that she also has the lowest record for the time of normal reproduction, as well as the lowest average time of learning the series in I. If we try to take this fact into account by finding the ratio between the rate for normal and for changed reproduction we find that she holds no longer the first place in the list, but, in I, the fourth, and, in II, the third. Moreover, neither of these modes of calculating would give us satisfactory results for all the subjects. Thus, taking the absolute time for the changed order, would give us the following arrangement of our subjects in order of their visualizing capacities: in I., C., S., T., H., P., Hs., in II, C., T., S., P., Hs.—neither of which lists corresponds with the order as indicated by introspection. But we find still less correlation if we take the order dictated by the ratios between the two rates, since we have then, in I., Hs., T., H., C. and S., P., and in II, P., T., C., S., Hs.

Apparently, then, we must conclude that the rate of reproducing such a series, whether taken absolutely, or with reference to the rate for normal reproduction, cannot be considered an unambiguous device for separating individuals with reference to imagery used. It might be successful in isolating the rather unusual persons who are able to retain a visual image as a whole in satisfactory form for reading off in any order, but it does not serve to point out the presence of visual images when they are partial and serial and only one part of a total complex.

If we turn to our tabulations on the basis of *accuracy* of the reproduced series, we find a similar amount of confusion and ambiguity. In the first place, we are again puzzled to know what

TABLE IX.

Time records (in seconds) for reproduction of letters in normal and in changed orders. N=Normal; C=Changed; Arrows represent direction in which reproduction took place, etc.

SERIES I.—TWO READINGS[1].

| | C. | Hs. | H. | P. | S. | T. |
|---|---|---|---|---|---|---|
| 1 N. ........ | 9.3 | 42.8 | 16.0 | 11.0 | 10.7 | 10.7 |
| 2 ↓ ........ | 22.2 | 37.2 | 27.8 | 33.8 | 27.0 | 23.3 |
| 3 ← ....... | 11.8 | 38.7 | 23.0 | 74.8 | 30.2 | 34.5 |
| 4 N. ....... | 6.0 | 10.0 | 23.2 | 30.0 | 10.7 | 24.0 |
| 5 ↑ ........ | 25.8 | 90.8 | 31.7 | 70.0 | 21.0 | 26.0 |
| 6 ↑ ........ | 35.0 | 68.0 | 26.7 | 57.5 | 18.0 | 27.2 |
| 7 N. ........ | 9.1 | 13.0 | 25.0 | 8.7 | 8.5 | 31.5 |
| 8 ↓ ........ | 9.5 | 27.0 | 34.0 | 49.7 | —[2] | 38.4 |
| 9 ← ....... | 12.1 | 42.2 | 31.9 | 29.7 | 10.3 | —[3] |
| 10 ↓ ....... | 15.0 | 55.0 | 36.7 | 38.7 | 30.0 | 27.5 |
| 11 N. ........ | 9.8 | 18.0 | 10.7 | 19.0 | 16.0 | 15.7 |
| 12 N. ........ | 6.0 | 32.0 | 25.0 | 12.5 | 8.5 | 8.0 |
| 13 ← ....... | 11.0 | 43.5 | 40.0 | 22.0 | 70.0 | 19.0 |
| 14 ↑ ........ | 24.7 | 59.0 | 53.0 | 26.0 | 47.5 | 29.0 |
| 15 N. ........ | 12.0 | 66.2 | 20.7 | 32.5 | 29.5 | 8.0 |
| 16 ↓ ....... | 19.0 | 20.5 | 50.5 | 34.7 | 23.8 | 26.0 |
| 17 ← ....... | 9.0 | 27.4 | 34.0 | 24.3 | 17.3 | 33.3 |
| 18 ↑ ........ | 22.3 | 62.5 | 29.0 | 40.0 | 16.0 | 35.0 |
| Av. .........N. | 8.7 | 30.3 | 20.1 | 18.9 | 14.0 | 16.3 |
| Av. .........C. | 18.1 | 47.6 | 34.9 | 41.7 | 28.3 | 29.0 |
| Ratio ...N.: C. | 1 :2.0 | 1 :1.6 | 1 :1.7 | 1 :2.2 | 1 :2.0 | 1 :1.7 |
| Diff. .....C.-N. | 9.4 | 17.3 | 14.8 | 22.8 | 14.3 | 12.7 |

SERIES II.—EIGHT SECONDS' EXPOSURE.

| | C. | Hs. | H. | P. | S. | T. |
|---|---|---|---|---|---|---|
| 1 ↓ ........ | 17.5 | 65.5 | ... | 20.1 | —[4] | 28. |
| 2 N. ........ | 10.5 | 14.8 | ... | 24.0 | 11.3 | 13 |
| 3 ↑ ........ | 19.0 | 53.8 | ... | 31.0 | 28.3 | 18. |
| 4 ← ........ | 10.5 | 142.5 | ... | 25.1 | 24.5 | 39. |
| 5 N. ........ | 7.0 | 12.0 | ... | 35.7 | 32.0 | 9. |
| 6 ↑ ....... | 15.4 | 93.7 | ... | 30.0 | 30.2 | 17. |
| 7 ← ....... | 12.9 | 45.8 | ... | 36.5 | 24.0 | 10. |
| 8 ↓ ........ | 13.4 | 101.8 | ... | 46.5 | 14.9 | 34. |
| 9 N. ........ | 10.6 | 30.3 | ... | —[4] | 17.1 | 8. |
| 10 ← ....... | —[4] | 43.9 | ... | 14.9 | 21.0 | — |
| 11 ↑ ....... | 10.2 | 120.0 | ... | 68.2 | 33.0 | 42. |
| 12 N. ........ | 6.9 | 44.7 | ... | 34.3 | 41.0 | 45. |
| 13 ↓ ....... | 11.0 | 140.0 | ... | 26.5 | 23.8 | 53. |
| 14 ← ...... | 8.9 | 46.1 | ... | 24.4 | 44.0 | 22. |
| 15 N. ........ | 8.5 | 20.0 | ... | 12.5 | 17.7 | 22. |
| 16 ↓ ........ | 11.0 | 45.0 | ... | —[5] | 68.0 | 30. |
| 17 ↑ ........ | 10.0 | 33.0 | ... | 37.0 | 45.0 | 18. |
| 18 N. ........ | 9.0 | 100.0 | ... | 20.0 | 12.9 | 27. |
| Av. .........N. | 8.7 | 36.9 | ... | 25.3 | 22.0 | 20. |
| Av. .........C. | 12.7 | 77.6 | ... | 32.7 | 32.4 | 28. |
| Ratio ...N. : C. | 1 :1.4+ | 1 :2.1 | ... | 1 :1.3 | 1 :1.5 | 1 :1.4– |
| Diff. .....C.-N. | 4.0 | 40.7 | ... | 7.4 | 10.4 | 7. |

[1] The average time taken by each subject for two readings was as follows: C. 5.9 sec.; Hs., 12.8 sec.; H., 11.1 sec.; P., 8.5 sec.; S., 10.8 sec.; T., 11.6 sec.

[2] Omitted. Wrong card given.

[3] Failure. Subject started in wrong direction.

[4] Time not recorded.

[5] Attention of subject distracted.

basis of comparison to use. It seems rather natural to assume that, if the non-visual subject is at a disadvantage, it will be chiefly with reference to the arrangement of the letters, rather than in the actual terms remembered, though the latter may be affected. We have, therefore, grouped under *a*, the percentage of letters correctly reproduced (*i. e.,* as belonging to the series, whether in the right position or not), and under *b* the percentage of correct letters correctly placed. We have then looked for the following possible correlations (see following paragraph): (1) We have noted the differences between the percentage of letters correct for the series and that of letters correctly placed, both for the normal and the changed orders, to see whether the best visualizers show less difference than do the other subjects, and whether they show less increase in difference for the changed order than do the others; (2) We have taken the values of the percentages for *b* for the changed order, without comparison with any other figures, to see whether the more visual subjects showed a higher record for absolute accuracy under the changed conditions than did the other subjects; (3) We have taken the ratio of the percentage of accuracy for *b* in the normal order to that of *b* in the changed order to see whether this showed less falling off for the more visual; and finally (4) we have taken the ratios of averages of the percentages of *a* and *b* for the two orders, to see whether it might be true that that the non-visual subject showed more general disturbance for the changed order than did the other.

None of these methods yield completely satisfactory lists of the subjects in the light of their own introspections, and some are quite contradictory. The lists which they would give are as follows (see Table X)[11]: (1) Difference between *a* and *b* for normal order (proceeding from lowest to highest)—S., Hs., T., C., P., H.; Difference between *a* and *b* for changed order—S., T., P. and C., Hs., H.; Slightness of increase in difference from the normal to the changed order—P., H., C., T., S., Hs. (P. showing a decrease rather than an increase): (2) Absolute values for *b* in the changed order, proceeding from highest to lowest—P., S., C., T., Hs., H.: (3) Ratios of accuracy of *b* normal to *b* changed (descending order)—H., P., C., T., Hs., S. (H. and P. showing an improvement in the changed order instead of a loss): (4) Ratios of general accuracy in the two arrangements, as indicated by an average of *a* and *b* (descending order)—H., P., C., T., S. and Hs. (H. and P. again showing an improvement in the changed arrangement).

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[11] We have presented only the results of procedure I, since II yielded essentially similar data.

It seems hardly necessary to comment on these results. If exact correlation is so lacking with these six subjects, it would seem to us hopeless to attempt to classify school children on the

TABLE X.

Accuracy of reproduction for normal and for changed orders. Given in terms of per cent. correctly reproduced. a, per cent. of correct letters; b, per cent. correctly placed; N, normal; C, changed, etc.

| Subject. | C. | | Hs. | | H. | | P. | | S. | | T. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | a | b | a | b | a | b | a | b | a | b | a | b |
| 1. N. | 77.7 | 66.6 | 88.8 | 88.8 | 77.7 | 66.6 | 100.0 | 100.0 | 100.0 | 100.0 | 88.8 | 88.8 |
| 2. ↓ | 77.7 | 55.5 | 100.0 | 100.0 | 100.0 | 77.7 | 100.0 | 100.0 | 88.8 | 88.8 | 77.7 | 55.5 |
| 3. ← | 77.7 | 77.7 | 100.0 | 100.0 | 88.8 | 44.4 | 77.7 | 55.5 | 66.6 | 55.5 | 77.7 | 77.7 |
| 4. N. | 100.0 | 100.0 | 100.0 | 100.0 | 77.7 | 66.6 | 77.7 | 55.5 | 100.0 | 100.0 | 88.8 | 77.7 |
| 5. ↑ | 100.0 | 100.0 | 100.0 | 66.6 | 77.7 | 77.7 | 77.7 | 77.7 | 100.0 | 100.0 | 88.8 | 88.8 |
| 6. ↑ | 77.7 | 77.7 | 44.4 | 22.2 | 33.3 | 22.2 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |
| 7. N. | 88.8 | 88.8 | 100.0 | 100.0 | 55.5 | 33.3 | 88.8 | 88.8 | 100.0 | 100.0 | 88.8 | 88.8 |
| 8. ↓ | 100.0 | 100.0 | 100.0 | 100.0 | 77.7 | 33.3 | 100.0 | 100.0 | ..... | ..... | 66.6 | 55.5 |
| 9. ← | 88.8 | 88.8 | 100.0 | 100.0 | 88.8 | 88.8 | 100.0 | 100.0 | 100.0 | 100.0 | .... | .... |
| 10. ↓ | 88.8 | 66.6 | 88.8 | 55.5 | 77.7 | 66.6 | 77.7 | 44.4 | 100.0 | 100.0 | 77.7 | 55.5 |
| 11. N. | 77.7 | 77.7 | 100.0 | 100.0 | 77.7 | 44.4 | 77.7 | 66.6 | 100.0 | 100.0 | 77.7 | 66.6 |
| 12. N. | 100.0 | 100.0 | 100.0 | 100.0 | 66.6 | 33.3 | 88.8 | 88.8 | 100.0 | 100.0 | 88.8 | 88.8 |
| 13. ← | 88.8 | 88.8 | 100.0 | 100.0 | 88.8 | 77.7 | 100.0 | 77.7 | 66.6 | 55.5 | 88.8 | 88.8 |
| 14. ↑ | 77.7 | 44.4 | 33.3 | 11.1 | 66.6 | 22.2 | 100.0 | 100.0 | 66.6 | 55.5 | 66.6 | 66.6 |
| 15. N. | 100.0 | 77.7 | 55.5 | 44.4 | 66.6 | 44.4 | 77.7 | 66.6 | 77.7 | 77.7 | 100.0 | 100.0 |
| 16. ↓ | 77.7 | 77.7 | 100.0 | 100.0 | 88.8 | 88.8 | 100.0 | 100.0 | 88.8 | 77.7 | 88.8 | 88.8 |
| 17. ← | 100.0 | 100.0 | 100.0 | 100.0 | 77.7 | 44.4 | 88.8 | 88.8 | 100.0 | 100.0 | 88.8 | 88.8 |
| 18. ↑ | 88.8 | 88.8 | 66.6 | 55.5 | 55.5 | 11.1 | 88.8 | 88.8 | 100.0 | 100.0 | 88.8 | 77.7 |
| Av. N. | 90.7 | 85.1 | 90.7 | 88.9 | 70.3 | 48.1 | 85.1 | 77.7 | 96.3 | 96.3 | 88.8 | 85.1 |
| Diff. a-b | 5.6 | | 1.8 | | 22.2 | | 7.4 | | 0.0 | | 3.7 | |
| Av. C. | 86.9 | 80.5 | 86.1 | 75.9 | 76.9 | 54.6 | 92.5 | 86.1 | 88.8 | 84.8 | 81.8 | 76.7 |
| Diff. a-b | 6.4 | | 10.2 | | 22.3 | | 6.4 | | 4.0 | | 5.1 | |
| Av. N. (a and b). | 87.9 | | 89.8 | | 59.2 | | 81.4 | | 96.3 | | 86.9 | |
| Av. C. (a and b). | 83.7 | | 81.0 | | 65.8 | | 89.3 | | 86.8 | | 79.2 | |
| Ratio N.: C. | 1 : .95 | | 1 : .90 | | 1 : 1.11 | | 1 : 1.09 | | 1 : .90 | | 1 : .91 | |
| N. b: C. b | 1 : .95 | | 1 : .86 | | 1 : 1.13 | | 1 : 1.11 | | 1 : .88 | | 1 : .90 | |

basis of such tests, objectively regarded. Judging simply from these data we should say that P. and H. must be abnormally visual, since both secure better percentages for the changed order than for the normal, yet their introspections indicate the reverse. We cannot be certain to what the improvement is due, but chance differences in the ability to work the letters into associative connections seem the most probable ground. The distribution of tests is such that practice would not affect one order more than the other. It may be somewhat true that the changed order, because of its greater difficulty, called out a higher degree of attention from the subjects than did the other, but the chances of this are lessened by the fact that the subject did not know, while learning the series, which method of reproduction was to be demanded. It may also be partially due to the fact that there are twice as many tests averaged under the changed orders as under the normal. Whatever the explanation may be, the fact is a striking indication of the difficulties in which we might find ourselves if we attempted to use this method on its objective side alone.

Another form of objective data which we have attempted to secure from this test has yielded results of interest though not of value for strict diagnosis, at least in what Segal calls an "inter-individual" use. This is the observation of the character of the errors—*like-sounding* vs. *like-appearing* letters—(See Table XI). It is evident that straight omissions will yield no material on this point, while misplacing or addition of letters may or may not. The most obvious thing about this list is the preponderance of like-sounding confusions over like-appearing. This tallies well with the introspective account of the importance of auditory or motor imagery for all the subjects. The results for H. indicate, in the light of her introspection, that a large number of such errors may be significant of motor tendencies and need not imply the presence of any auditory imagery. In certain cases the introspection of the subject contradicts the objective indications of an error, showing that the mistake was due to some other condition, such as misleading associations, faulty reading of letter, etc.

TABLE XI.

*Record of Errors. Both Series.*

| Subj. | No. of errors. | Like-sounding. | Like-appearing. |
|---|---|---|---|
| C. | 37 | 14<br>3B-V, 1T-V, 2D-T, 1T-D-V, 1T-D-B, 1L-F, 1S-F, 1G-J, 3G-Z. | 0 |
| Hs. | 82 | 14<br>1D-V, 6B-T, 1D-T, 1V-B, 1D-B, 1X-S, 1X-F, 1J-G, 1L-N. | 2?<br>1R-B (1K-X. Hs. said he misread K as X in learning). |
| H.[1] | 78 | 12?<br>1B-V, 2T-Z, 1G-Z, 2L-F, 1L-S, 1 S-N, 2F-S, (2N-M). | 3?<br>1P-R (2N-M). |
| P. | 67 | 11<br>1B-V, 2P-D, 1P-T, 1Z-V, 1N-S, 1X-S, 1L-N, 1L-F, 1C-Z, 1P-B. | 2?<br>1B-R-P (1X-K. P. said, "Not vis. confusion"). |
| S. | 37 | 3<br>1B-V, 1D-Z, 1D-V. | 1?<br>1X-K. |
| T. | 64 | 5?<br>1S-X, 2D-G, 1Z-V, 1G-Z (1E-Z. Due to assoc). | 3?<br>1K-H (1V-W. Due to assoc.), (1X-K. Misreading?). |

[1] Results for H. represent one series only.

### e. DESCRIPTION OF PICTURES.

In these tests we have material again which is more like that of a.—Reading—and d.—Remembering colors, forms, etc., *i. e.*, it presents a possibility of dependence either upon a memory image, which must be visual, or visual and eye-motor, or upon verbal descriptive images, which may take any form. These tests were introduced into the series late, since we had not considered them very desirable materials to use for several reasons: (1) They seemed to represent less satisfactory materials from the scientific standpoint, since, by their complexity, they make it impossible to isolate the various factors, such as form, color, etc.; (2) Moreover, the factors of meaning and associational connections, which we had found disturbing even in our disconnected groups of materials, are magnified here and practically forced upon the subjects; (3) From the standpoint of calculating the results they present extreme obstacles, since it is far more difficult to determine what "grade" a given subject should have for the reproduction of the details of a picture, than what he should have for the reproduction of a series consisting of clean-cut elements.

All these reasons, however, we have come to consider as overbalanced by the actual contributions of the method. Whatever may be the advantages of isolating the various factors of the situation for the study of any mental process—and we would not minimize these—we have become convinced that, for imagery at least, we cannot be sure of correct interpretation, if we assume that the imagery used in a complex situation will be the sum of the imagery used for its isolated elements. This represents the fundamental ground for introducing these tests, since we found that, with certain of our subjects, we succeeded in tapping a source of imagery (visual in this case) not suspected from the tests with isolated forms and colors. As to the second point, while we deplore the presence of these other factors, it seems possible that there may be less variation between subjects in this respect because of the very fact that meaningful connections are so obvious that all the subjects use them, while for the other tests only those most expert in developing such associations had the advantage which this gives. The third point, that of the difficulty of tabulating results, has not been solved, but has been met with an attempt to minimize the errors arising from clumsy technique. This method will be described in the account of the objective results of these tests.

There was no fundamental difference between Series I and Series II, except for the difference in time intervening before description of the picture, and the fact that in the former series we included both colored and uncolored pictures.[12] The former series also came first chronologically, since they included all the pictures which we originally planned to use. The latter series was introduced for two purposes: (1) to add more material for comparison of objective results, and (2) to see whether we could discover any training value of such a series. (The latter phase of the experiment will not be discussed in this section.) In the second series, we discontinued the practice of giving one and two-day intervals, since that furnished no essentially different introspective data and complicated our procedure.

We shall present, first, the introspections on the two series, then our formulation of the accuracy and completeness of the description for comparison with the introspective accounts. We shall include here only the descriptions given immediately and after one day, since the others were left incomplete. Eight subjects

[12] There was also a difference in the directions given, since in the latter we asked the subject to make a definite effort to obtain good visual images of the pictures. We did not ask him to eliminate other factors, such as naming and eye-movements, as these often helped to clarify and fix the visual images.

## TABLE XII.

*Introspective Observations of Subjects.*

Series I.

| Test. | Ad. | C. | Hs. | H. | P. | S. | T. | V. |
|---|---|---|---|---|---|---|---|---|
| Immed.<br>Uncol'd | | | | | | | | |
| 1. | *Verb.,* vis. | *Vis.,* verb. | *Vis.* (verb.) | *Verb.,* vis | *Vis.* | *Vis.,* verb. | *Verb.,* vis. | *Verb.,* vis. |
| 2. | " " | " " | " " | " " | " (verb.) | " " | " " | " " |
| Col'd | | | | | | | | |
| 1. | " " | " " | " " | " " | " | " " | " " | " " |
| 2. | " " | " " | " " | " " | " " | " " | " " | " " |
| 1 day.<br>Uncol'd | | | | | | | | |
| 3. | *Verb., vis.* | *Vis.* (verb.) | *Vis.,* verb. | " " | " ("?) | " " | " " | " " |
| 4. | " " | " " | " " | " " | " " | " " | " " | " " |
| Col'd | | | | | | | | |
| 3. | " " | " " | " | " " | " " | " " | " " | " " |
| 4. | Omitted. | " | " | " " | No reprod. | " " | Verb., *vis.* | " " |

Series II.

| Immed. | Ad. | C. | Hs. | H. | P. | S. | T. | V. |
|---|---|---|---|---|---|---|---|---|
| 1. | *Vis.,* verb. | *Vis.* | *Vis.* (verb.) | *Vis.* (verb.) | *Vis.,* verb. | *Vis., verb.* | Vis. (verb.) | *Verb.* (vis.) |
| 2. | " " | " | " " | " " | " | | Vis., verb. | " " |
| 5. | " " | " | " " | " " | " " | " " | " " | " " |
| 6. | " " | " (verb.) | " " | " " | " | " " | " " | " " |
| 10 min.<br>interval. | | | | | | | | |
| 3. | Vis., *verb.* | *Vis.* (verb.) | " " | " " | " (") | " " | *Vis., verb.* | " " |
| 4. | *Vis.,* verb. | " | " verb. | Vis., *verb.* | " (") | " " | " " | " " |
| 7. | " " | " | " (") | Vis., verb. | " " | " (") | " (") | " " |
| 8. | " " | " (verb.) | " " | Vis., *verb.* | " " | " " | Vis., *verb.* | " " |

*Note:* In the above we have used the term "verb." to cover all naming of objects in the picture, instead of doing as in preceding tables and indicating by form of imagery—aud., artic., voc.-mot., etc. We have done this for the sake of compactness, and because this was the way in which the subjects tended to express themselves. Naming was apparently never done in vis. terms, so that vis. applies solely to (concrete) memory imagery, while the verbal imagery takes the form, other than vis., normally used by the subject in other tests.

The left-hand column gives the number and character of the test, indicating whether the picture was colored (Col'd) or uncolored (Uncol'd) and whether reproduction took place immediately, after 10 minutes, or after 1 day. All pictures in Series II were colored.

We have omitted in the table references to general motor imagery or tendencies to movement, often of a dramatic character, mentioned by several of the subjects—Ad., H., S., V.—as frequently of considerable importance. T. reports in several cases the use of eye-movements as an aid, especially when she was trying to visualize.

were used for these tests: Ad., C., Hs., H., P., S., T. and V. Series III is sufficiently different from the other two to deserve separate treatment, which will follow the discussion of Series I and II.

Before discussing the above table, we should note that there are certain variations in procedure which we could not represent in the table. These are concerned especially with the character of the visual imagery. Thus, we find P. (and T. in some of the tests) reporting complete or almost complete dependence on visual imagery, as do C. and H., yet there is a great difference in the adequacy of this imagery as described by the subjects. P. frequently characterizes his imagery in this, as in other tests, as indefinite, not rich in details, the kind which is just about to develop but does not quite succeed, etc. T.'s imagery is even more strikingly defective, scrappy and vague. The emphasis on this and the diminution of verbal material seemed to come wholly in the attempt to comply with the directions and summon a "good visual image." With C., Hs., P. and S., the visual imagery furnishes many details not suggested by the verbal imagery; this is somewhat true for Ad. throughout, but more strikingly so for Series II; H. and T. sometimes fill out partial details thus, such, for example, as the direction in which a child is facing, but are much less apt to get any whole object in this way. V. practically never gets any help from the visual. All that she recalls seems to come as an accompaniment to the verbal description which she gave to herself when she looked at the picture, and which she has retained as so many words. S. reports, as usual, a profusion of visual imagery, but feels hampered by the fact that he can not rely on this. If any question arises as to the presence of an object in the picture, he is apt to insert this at once into an appropriate setting. In these cases, articulatory imagery frequently has to enter to decide, and often the absent object is introduced into the account. The verbal which he uses is much more apt to appear while he is looking at the picture than while describing it afterwards, though he often says that the things which remain visually are the things which he named while looking. With H., this process of naming as many things as possible during inspection was always present, even where she indicated, as she did in certain cases, that the verbal imagery was less prominent and helpful than the visual. This statement of hers applied only to the recall, and not to the process of learning.

If we take into account these variations, we may group the subjects somewhat as follows, with reference to the visual imagery used: C. and Hs., profused and detailed; Ad., slightly less so, but still good, especially for Series II; S., somewhat more profuse and detailed, but recognized as inaccurate; P., fairly profuse, but vague and ill-defined; H., less abundant, subject more dependent on verbal stimulus (latter always used while looking at picture); T. and V., subjects predominantly dependent on verbal, though not utterly lacking in visual, the former (T.) succeeding in some cases in using it without the verbal

The chief difference to be noted between the two series is the greater degree of dependence upon visual imagery reported in the second series. We do not know to what to attribute this, unless it be the request of the experimenter that more visual be used if possible, though it may be also due to some extent to an improvement in the visualizing capacity of the subjects.

In the series as a whole, the most striking thing is the large amount of visual imagery reported, as compared with any of the other tests, such as the memorizing of colors and forms (see p. 69-70). In the latter, for example, Ad. reported no visual imagery and H. reported very little, while C. and P. noted much less exclusive dependence on it than in the present case. On the whole, judging from the eight subjects used here, it seems true that the tests with pictures are more effective in stimulating visual imagery than are any of the other tests thus far reported, with the exception possibly of certain of the more effective reading passages.

Objective Results. The preparation of the data for comparison with the introspective material was by no means an easy task, because of the difficulty in estimating the relative value of the details described. As a matter of fact, we have not attempted to do this, except to the extent of comparing one subject with others on an even basis. For example, if all subjects report a team of horses, it seems immaterial whether we credit them with one or two points. But if certain subjects mention only one horse, we need a system of marking which will allow us to differentiate between the two cases. In order to insure this degree of fairness, we made it a practice to check up one item for all the lists before proceeding to the next item, etc. It was thus easy to observe differences in detail, which might have escaped us if we had made the count by subjects: *i. e.,* if we had counted all the items given by one subject, then all given by the next, etc. As an aid to this comparison, the lists were all typewritten in columns, so that it might be easy to pass from one to another. The details were then counted on a constant though arbitrary basis. This method is evidently crude and incapable of a high degree of accuracy. Yet, when very obvious and striking differences appear, they seem significant. It is these, therefore, of which we are in search in these results.

In the first series, only very rough indications are evident, and negative cases are not lacking. The average number of details reported by each subject for each group of pictures is as follows:

Uncolored Pictures: Hs., 16; C., 15; Ad., 14; P., 13.5; S., 13; H., 11; T., 9; V., 8.
Colored Pictures—Objects: Ad., 13.3; C., 12; Hs. and S., 10; H., 9; T. and V., 8; P., 7.
Colors: C., 8; Ad., 6.6; Hs., 6; H., 5; V., 4.5; S., 4; P., 3.5; T., 2.
Total: Ad. and C., 20; Hs., 16; H. and S., 14; V., 12.5; P., 10.5; T., 10.

These lists show a general trend of the results in accordance with the introspections, in that the best visualizers are most in evidence at the beginning of each list and the worst visualizers at the end. A comparison of averages for immediate reproduction with those for delayed shows rather less correlation for the former than for the latter.

When we turn to the results for Series II, we find a greater degree of correlation. We do not know what is responsible for this change, but the evidence is very striking. In the following account we have tried to present the results in such a way as to throw this correlation into prominence. The data were calculated in the first place as for the preceding series, but, in order to do away with absolute numerical variations which are incidental to external conditions (such as the amount of detail in the picture given), we have first found the average number of details reported for any given picture, from the records of all the subjects. We have then determined the relation which each subject bears to this average, whether he is above or below it, and how much. This relationship is expressed in terms of a percentage of the average for the given picture, which is considered as 100%. Table XIII gives the results of this tabulation:

TABLE XIII.

PICTURES. SERIES II.

*Grading of Subjects with Reference to Number of Details Reported.*[1]

| | *Immed. recall.* | | | | *Recall after 10 min.* | | | |
|---|---|---|---|---|---|---|---|---|
| No. of picture | 1 | 2 | 5 | 6 | 3 | 4 | 7 | 8 |
| Average for picture | 18.75 | 21.6 | 11.75 | 20.0 | 17.8 | 16.0 | 17.3 | 18.1 |
| Subjects. | | | | | | | | |
| Ad. | 112% | 111% | 144% | 112% | 118% | 125% | 136% | 135% |
| C. | 128 | 134 | 137 | 132 | 107 | 125 | 124 | 116 |
| Hs. | 149 | 129 | 119 | 125 | 152 | 119 | 133 | 124 |
| H. | 69 | 101 | 85 | 95 | 50.5 | 94 | 81 | 77 |
| P. | 101 | 118 | 85 | 92 | 95 | 100 | 78 | 89 |
| S. | 154 | 90 | 102 | 120 | 127 | 100 | 115 | 99 |
| T. | 32 | 41 | 42 | 57 | 76 | 56 | 58 | 77 |
| V. | 59 | 71.7 | 85 | 65 | 76 | 81 | 75 | 83 |

By these, we see a tendency of Ad., C. and Hs. to keep constantly above the average, of P. and S. to be sometimes above and sometimes below—S. being more above on the whole, and P. more below—but of H., T. and V. to be regularly below. In other words, the three subjects who use visual in this test to a great extent come out with the most evenly good results; the one—S.—who has profuse but non-dependable imagery comes out fairly well, but is more erratic, as is also P., who suffers from the vagueness of his imagery, while the three—H., T. and

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[1] The rating of the subjects was determined in the following manner: The average number of details reported by all the subjects was first found. This number was then considered 100% for the given picture, and each individual record graded accordingly. This is an arbitrary method of grading which enables one to tell at a glance the relation of each subject's record to the average.

V.—who show most complete dependence on words and least use of visual imagery, very consistently bring up the rear.

A certain interest attaches also to the number of incorrect details added by the various subjects. While we have not attempted to use "Aussage" methods and hyper-induce the subject to insert incorrect elements, we have noted all such additions which occurred naturally, and, by means of quizzing with regard to the exact character of these objects, have often led to their elaboration. If we arrange the subjects in order according to the total number of details added in the reports of these eight pictures, we have the following list, passing from lowest to highest: T. (3), V. (5), H. (11), P. (13), Hs. (15), C. (24), Ad. and S. (33). It appears from this that the subjects who ranked highest by the positive reckoning tend to reverse the situation, when viewed in the light of insertion of incorrect items, while those who gave the most scanty reports of correct items, show a similar scarcity of errors. Apparently, in this group of tests, the better visualizers are characterized by greater profuseness of imagery rather than by greater absolute accuracy, measured by freedom from errors. This fact tallies well with certain of the introspective comments, *viz.,* the insistence by T. and V. that their difficulty lay, not in deciding between various possible details, but in recalling any; on the other hand, S.'s repeated statement that his visual imagery was so abundant and so readily stimulated that he had difficulty in deciding which of the elements before him in recall had actually been present. The errors of the better visualizers most frequently took the form of attempts to fill out the imaged picture in consistent fashion, whereas this tendency was reduced to a minimum in the non-visual subjects.

Series III. This series, as here presented, is in a crude state and is offered mainly as a suggestion. For some time we had been convinced that the processes involved in studying a picture for purposes of recall were not identical with those of normal observation of a picture with subsequent recall. Yet we did not wish to ask for reports on pictures or objects which had simply been available for observation, but which might never have been observed. Evidently a device to meet these two needs must combine attention to the picture with ignorance of its purpose. While we were attempting to plan such a method, we happened to attract the attention of one of our subjects to these puzzle pictures. As he examined them, it occurred to us that this offered the very situation which we wished. The subject was intent on the search for the concealed object, and was considering the picture from that point of view alone. Yet he was giving visual attention to every part of the picture. The scheme was devised at once, and the subject was surprised ten minutes later by a demand for a description. In this hurried development of the plan certain imperfections were introduced. In proposing the test for future use, therefore, we would suggest that certain changes be made:

(1) We should not use as many as four puzzle pictures, since they proved mutually confusing. We should try simply one, or at most two, relying on other methods for further data. (2) While it is impossible to time the subject exactly as for other pictures without exciting his suspicions, we should limit the time approximately. If the subject had not found the concealed object by this time, we should point it out to him and proceed to the next picture. In the present work there was considerable variation in the amount of time given to the pictures by the different subjects, but no correlation seemed to exist between the amount of this and the excellence of the recall. (3) Unless several other methods were devised to furnish a larger mass of data, we should ask for immediate recall in every case, and not attempt to estimate the effect of an intervening day or two.

The other method used has been described on p. 27. It was sufficiently natural for the author to be reading a book on imagery and to call the attention of others to it, so that the subjects easily fell into the trap of looking at the picture, in spite of their previous experiences with the puzzle pictures.

In every case we took great care that the presentation should be so perfectly natural as not to arouse suspicion—and we succeeded in this effort. Numerous other methods might be devised and should be added, if the objective material is to be employed. The method can not be used indefinitely, however, since each time that it is used makes it harder to use it successfully again.

In spite of the crudities of our procedure, the results proved instructive. (1) The general meagerness of detail in the reports, as compared with the descriptions of pictures in Series I and II, was noteworthy. The recollection tended to center entirely about the hidden objects or the places of their concealment, in spite of the fact that other parts of the picture had often been studied attentively for these objects. Apparently there is a different type of attention which is given to an object when it is studied to be remembered from that which is given to it for other purposes. This may be partially a question of the degree to which the tendency to develop "word tags" for the various details is present; which suggests our second point.

(2) On the whole, there was much more exclusive dependence upon visual imagery than in the earlier series. This does not mean that there was more or better visual imagery, but rather that there was less verbal. With the earlier pictures, the introspections had shown that all the subjects used some verbal imagery in learning the pictures, and that most of them relied on this for help. (P. was the only one who seemed to receive practically no assistance from it.) Three subjects—H., T. and V.—based their learning almost entirely on the use of names. Visual imagery, even when present, was usually secondary and called up by the name. In Series III the method was quite different. The majority of the subjects observed no tendency to naming, either while looking at the picture or as a means of recall. The difference in the case of H. was most striking. Whereas, in the preceding series, she spent the whole period of inspection in a rapid naming of the objects of the picture and depended largely on these words in the recall, nothing of the sort occurred here. An occasional "articulatory" image appeared, as a result of the fact that she usually commented on the location of the concealed object when she discovered it. T. also practically discarded her method of careful naming, though in one case she said that she remembered a certain detail because she

had commented upon it. In general, she remembered what little she did in terms of vague, visual imagery and "reasoning." (For example, when she remembered that "Snowdrop's" hair was streaming out behind, that suggested, as a logical consequence, that she was running.) V. showed most persistence of a dependence on verbal materials, though these were very inadequate for this work. What she remembered was almost entirely what she had remarked about, either aloud or to herself, at the time of inspection.

(3) A comparison of the objective results of the different subjects proves interesting, also. As we have pointed out, an exact comparison is not warranted in the case of the puzzle pictures, because of the variations in the time devoted to inspection by the different subjects. This variation did not exist for the final picture (Tafel 1, Urbantschitsch, 111), but A. and Hs. were not given this picture. With the puzzle pictures, however, the interesting fact appears that the excellence seems to bear no close relation to the amount of time given to observation of the picture. Thus A., who gave very full reports, took a relatively long time for study of the picture, but so also did H. and V., whose reports were notably scanty. On the other hand, Ad. was one of the most rapid and his descriptions were relatively full, although it is quite probable that his accounts would have been somewhat better if he had given a longer time to inspection. In spite of the variations, then, the fact remains that we find rather a sharp dividing line, in the case of the puzzle pictures, between the fullness of the descriptions of subjects A., Ad., C., Hs., P. and S. on the one hand, and H., T. and V. on the other. There are slighter variations within these groups, but the classification of these two sets as fairly good reports *versus* very poor is based on large differences. It will be noted that the three of the last group had been poorest with the other series, for the learning of which they had employed least visual imagery and had depended most on verbal. Here, where the verbal is practically not available, they find themselves almost helpless. H. is the most striking instance of this, for she had developed the most satisfactory technique for naming objects, which brought

her reports nearer to the average than those of T. and V. For the puzzle pictures, however, she drops quite down to their level.[13]

The final picture, the illustration from Urbantschitsch, gave results which differed in certain important respects from the above, a fact which illustrates the desirability of gathering further data by this general method, before it can be used in any objective way. The picture is rather unusual, both in the details presented and in the perspective. For example, the position of the dog is such as to force the attention of all the subjects to this detail. Moreover, report on this picture was given immediately, instead of after a delay of ten minutes. These facts perhaps account for the improvement shown by H., both in the character of her visual imagery and in the relative amount of detail reported. By our count the number of correct details given by each subject is as follows: C., 17; H., 14; S., 14; P., 10; T., 9; V., 4. The number of incorrect details added: C., 6; H., 4; S., 12; P., 1; T., 2; V., 1. As in the case of the earlier series, it does not appear that the subjects with the poorest accounts are those who add most incorrect details: *i. e.,* their failure is not due so much to imaging things wrongly as to inability to image them at all. On the other hand, the vigor of S.'s productive imagination for visual materials is well attested by the additions which he makes. (For example, he has the woman decked out in the conventional black dress, white apron and cap of a maid, instead of in the spotted blue dress, pinkish apron, red shawl and black hat which she actually wears.) Again, T. and V. are at the end of the list for correct details, though T. is only one behind P. V., however, sustains her record for poor recall of visual materials, since even the four items which we have credited to her are of the most general sort—"lot of figures," "women," "children," "house."

Conclusions with Regard to Series III. We are convinced that the method of securing a report of this sort from subjects, under conditions of lack of anticipation of such report, is a desirable one to use both for the sake of the introspective material stimulated and for the objective results. Its special

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[12] For illustrative data on one puzzle picture, see Appendix, p. 159 ff.

advantage on the introspective side is the fact that it furnishes information with regard to the normal processes of observation and recollection of concrete materials. The objective results, as we have indicated, show a certain degree of correlation with the introspective reports. While we do not seem justified in relying upon this for exact measurements, marked differences seem valuable for diagnosis. That is, a large amount of correct detail seems characteristic of the more visual subjects, while a small amount is representative of the relatively non-visual. At the same time, it does not appear that a large proportion of incorrect detail is indicative of the latter group rather than the former. On the contrary, these tend to show less additions and substitutions, as well as less that is correct.

A special point of interest for us in connection with this test was the consideration of its value as a measure of improvement along visual lines. Since it seems possible that much which is usually ascribed to improvement of imagery may be simply greater attention to visual objects for purposes of recall—in other words, improved technique of observation—we wished to have certain methods which would take the subjects off their guard, and which might be applied at the beginning and at the end of a training series.

### f. DRAWING.

(For Description, see p. 27.)

The tests involving drawing were, unfortunately, left incomplete. Only three subjects—Ad., C. and Hs.—were tested, and these with an extremely short series. We have cited these tests, however, since they seem to us desirable members of a diagnostic series, especially if such a series were primarily concerned with imagery factors in relation to movement. The results which we did secure offered nothing radically new, though kinæsthetic imagery (in the form of hand-motor) appeared more prominently than in any of the other tests. C., however, reported none of this, relying wholly on visual imagery.

In this connection, reference might well be made to such tests as those devised by Miss Downey (37) for studying writing controls. Our reasons for not including these tests in our series were, first, the fact that she had explored the field so carefully, using three of the subjects who later served for us, and, in the second place, the fact that her results showed such complexity in the performance of these tests that they did not appear to offer any peculiar advantages for diagnosis. That is, they seemed neither to furnish objective criteria of image forms, nor to offer special inducements for the arousal of a particular kind of imagery, whereby the introspective observation of this form might be made easier. They belong, therefore, in the same class with such tests as ours on reading, in that they offer an opportunity to study imagery as it is actually used in an important and common form of action.

### g. LISTS OF WORDS GROUPED ACCORDING TO SOUND OR SPELLING.

In these tests we return to less complex materials, in that we are dealing with the word form and are not concerned with the character of its meaning content. Accordingly, we are simply concerned here with verbal imagery, and any reference to visual, auditory, etc., may be understood, without further specification, as applying to this.

*Lists of Words Rhyming with a Given Word.* The following words were given in this series: Speak, low, home, case, hope. The subject was given one minute in which to write all the words of which he could think, rhyming with the given word. No attempt was made to use these as objective tests, since it became evident at the start that other factors than type of imagery were effective in determining the actual number of words given. At the same time, the ability to perform this test at all seemed an indication that the subject must have the use of some form of verbal imagery other than visual, a fact of which we had already been convinced by the introspections on previous series and which appeared even more strikingly in the introspective side of these tests.

The test, as a whole, seemed to appeal much more effectively to the auditory-vocal-motor complex than to the visual. All the subjects reported some form other than visual, only one—Sun.—holding that the visual had any importance in calling up the words of the lists. Only those subjects who had reported strong visual verbal in other tests, such as spelling backwards and pronouncing from words spelled backwards (C., G., Hs., S. and Sun.) used any visual at all, while A., who belongs with this group in the other tests, used none. Those subjects who used only a slight amount under the other conditions used none here. The scope of imagery reported by the different subjects may be indicated thus:

| | | | *No. Vis.* | | |
|---|---|---|---|---|---|
| *Aud.-mot.* (some vis.) | *Artic.* (slight vis.) | *Artic.*, *vis.* | *Aud.-voc.* | *Artic.* | *Aud.* |
| C., G., Hs. | S. | Sun. | A., Ad., T. V. | H. | P. |

*Lists of Words Ending in Certain Letters Regardless of Sounds.* The following endings were given as a basis for the lists of words: ough, ose, ome, ave, one, ate, ine, ore. As in the preceding case, one minute was given for each list, with the exception of the last two, for which two minutes were given. Again we have relied solely on the introspective aspect of the tests, since we have found no interesting correlation arising from the objective results. We have tried especially to elicit information from the subject with regard to the following points: (1) The way in which the words suggested themselves; (2) whether any words presented themselves which agreed with the rest as to sound, but had to be rejected because the spelling did not accord with the conditions; and, if so (3), by what means they were rejected.

With regard to the first of these points, the majority of the subjects reported that the words came substantially as for the preceding tests, though there was no need of retaining the sound similarity. C., G., P. and S., however, reported more visual imagery here than in the rhyming series, especially for the first ending—"ough." C., for example, says with regard to this: "Did not pronounce words because the different pronunciations are so unlike. Depended on visual word image largely; kept 'ough' in mind and fitted letters in front of it." A., Ad., H., T. and V. still reported an absence of visual imagery for this part of the process.

For the rejection of words which did not belong in the list, more visual imagery tended to appear, though this rejection might be accomplished by spelling the word. For example, with the ending "ome," if the list has started as "home," "dome," "tome," etc., "roam" might naturally present itself but be discarded because of the visual dissimilarity of the ending, or because the spelling showed it to be wrong. The following subjects discarded on the basis of *visual* imagery: A., C., G., Hs. (P.); the following by spelling the word through: Ad., Hs., H., T. (V.). P. and V. had little occasion of testing this process, as few words came to them which had to be rejected. Hs. appears in both groups, since he made use of both methods.

*Lists of Words Ending in Certain Letters, but Grouped According to Sounds.* (See illustration, p. 28.)

The endings given here were: are, ove, oth, ear, ead. Two minutes were given for writing each list. The results may be omitted, since they add nothing of importance to the preceding tests, but represent rather a combination of the two methods.

### h. and i. PROBLEMS.

Our earlier work has indicated clearly that the more distinctly problematical a situation becomes the more prominent do the imagery controls appear. It seemed desirable, therefore, to investigate the field of problems somewhat more fully. This opens a practically unlimited field, but we confined ourselves to two groups, arithmetical and physical problems. Moreover, in these tests, as in those involving drawing, we were forced to leave the work incomplete. Since they brought out no essentially new factors we may summarize the results very briefly.

### h. MATHEMATICAL PROBLEMS.

Since no correlation could be discovered between speed and accuracy on the one hand, and the character of the imagery on the other, we shall refer only to the introspective results. Only six subjects were tested—A., Ad., C., G., Hs., S.—a group of rather strongly visual subjects on the whole, with the exception of Ad. The reports may be briefly summarized as follows:

A.—Vis. and aud.-mot. in varying degrees. Vis. apparently most prominent.
Ad.—Aud.-voc.-mot. No vis.
C.—Vis. and aud.-mot.
G.—Vis. and aud.-mot.
Hs.—Vis. (including number form), lip-mot. and slight amount of aud.
S.—Vis. and artic., latter apparently more important.

It appears from this summary that the same general distribution of imagery obtains as for the non-verbal imagery in the reading, normal spelling, memory tests for letters and words, etc., except that visual imagery seems more important. Yet the same peculiarities are evident, viz., Ad. makes no use of visual and S. none of auditory, Hs. is very dependent upon lip-motor factors, while the other subjects show a division of labor, using the different forms more or less indiscriminately.

It must be remembered, however, that the above is merely a summary, which as such can take no notice of many individual differences in the characteristics of these images and the ways in which the various kinds are used. A detailed account would show complexities similar to those described by Brown (24) in his discussion of mathematical processes.

Our statement also disregards many factors of importance other than imagery. We have artificially separated references to imagery from their context, because of the use which we were now making of these tests. The following example, taken from G.'s introspection on one of the most difficult problems, suggests the complexity of processes which may appear:

> "I seemed to use my whole muscular system, using my fingers to hold some of the numbers, and using the whole trunk in reinforcing some of the visual images. I also used some associational factors for hanging on to some of the numbers: *e. g.*, in 61,424, the '61 as the Civil War period. In 424 I think the symmetrical appearance was a help."

In the simpler tasks tendencies to automatisms were much in evidence, bringing with them a diminution in imagery controls. It was for the sake of breaking up these tendencies that we introduced the tests with Roman numerals, a work which they effectually performed. No new points for diagnosis appeared, however, except as the imagery was more prominent and felt to be more indispensable. In no case was the operation performed as a sheer automatism, since there was always at least the translation of the Roman form into either the Arabic form or the name of the number.

### i. PHYSICS PROBLEMS.

In the selection of physics problems we were guided by the desire to secure questions which might stimulate concrete imagery, rather than merely verbal. Only five subjects were used—Ad., Hs., H., T., V.—of whom Hs. is the only one who has shown himself consistently visual, though Ad. has been so on occasion. In every case the problems were of a simple character and quite possible of solution by this group of subjects. The following four problems are representative of the group.[14]

"Suspend a weight by a string. Attach a piece of the same string to the bottom of the weight. If the lower string is pulled with a sudden jerk, it breaks; but if the pull is steady, the upper string will break. Explain." (P. 37, 5.)

"Will the water line of a boat rise or fall as it passes from fresh into salt water?" (P. 56, 3.)

"Why do fine bubbles rise in a vessel of water which is being heated long before the boiling point is reached? How can you distinguish between this phenomenon and boiling?" (P. 207, 5.)

"Why will a moistened finger or the tongue freeze instantly to a piece of iron on a cold winter's day, but not to a piece of wood?" (P. 219, 4.)

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[14] The following 11 problems were selected from Millikan and Gale's "First Course in Physics": P. 37, 5 and 13; p. 56, 1 and 3; p. 145, 1; p. 207, 5 and 12; p. 215, 3; p. 219, 2, 3, 4.

As in the case of the preceding problems we may summarize the introspections without discussion of points of detail.[15]

Ad.—*Vis.* (definite and good), *kinæsthetic,* tactual, olfactory, *verbal.*

Hs.—*Vis., kinæs.* (decided), tactual, temp. (?), verbal.

H.—Vis. (slight and vague), kinæs., *verbal.*

T.—Vis. (shadowy), kinæs., *verbal.*

V.—Vis. (slight), aud., temp., pain, *kinæs, tactual, verbal.*

The most important forms of imagery for the solution of these particular problems are apparently visual, kinæsthetic and verbal, with the emphasis on the latter. Numerous comments were made with regard to the functions of the imagery used, the subjects sometimes insisting on the importance of concrete imagery for the solution of the problem, and sometimes declaring that all the rest was merely an accompaniment to the verbal, which was their sole dependence.

The tests as a whole proved themselves valuable, both by the arousal of a variety of forms of concrete imagery, and by the opportunity which they afford to study the functions of imagery, both verbal and non-verbal. Other fields, such as chemistry, physiology, geometry, etc., would offer similar material, which might be utilized with profit.

### j. SUMMARY OF DIAGNOSTIC RESULTS OF PRELIMINARY TESTS.

Though we started out quite ambitiously as to the scope of the field which we should investigate, as indicated, for example, in the reading tests, we have been forced by the demands of the situation to narrow this range. This has meant that we have confined ourselves chiefly to the investigation of the various forms of verbal imagery and to visual non-verbal imagery. Our attempts at more accurate diagnosis and at training have been directed toward some aspect of these forms. As an explanation of the directions taken by our next group of tests we may summarize briefly the results thus far obtained.

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[15] The forms mentioned as most satisfactory or most prominent are italicized. As in the tests with pictures, the term "verbal" is used for all imagery which is not "concrete." It might, of course, appear in any form, but in these tests visual verbal was never reported.

## TABLE XIV.

*Summary of Diagnostic Indications of Preceding Tests.*

| | Verbal Imagery. | | | | | Visual Non-verbal. | |
|---|---|---|---|---|---|---|---|
| Test. | Vis. | Aud. | Voc.-mot. | No vis. | No aud. | Reported. | None. |
| Reading. Reprod. | A., C., G., Hs., P., S., Sun. | A., Ad., C., G., Hs., P., T., V. | All. (P. little.) | Ad., H., T., V. | (H., S., Sun.?) | All. | No subjects. (H., T., V. very little.) |
| Spelling. | A., C., G., Hs., P., S., Sun. (T.?). | do. | do. | Ad., H., T.,? V. | H., S., Sun. | | |
| Pronouncing. | A., C., G., Hs., P., S., Sun. | do. | do. | Ad., H., T., V. | do. | | |
| Memory (a) | do. (P. little.) | do. | do. | do. (P. little.) | do. | | |
| " (b) | No subjects. | do. | do. | All. | do. | *A., G., Hs., S., Sun.*—C., P., T.—(H., V.). | Ad. (H. and V. very little.) |
| * Pictures. | No subjects. | do. | do. | All. | do. | All.* *Ad., C., Hs., S.,* P., Ha. (T., V.). | No subjects. (H., T., V. least.) |
| Rhyming. | C., G., Hs., S., Sun. | do. | do. | A., Ad., H., P., T., V. | do. | | |
| Same ending. | A., C., G., Hs., P., S., Sun. | do. | do. | Ad., H., T., V. | | | |

* A., G., Sun. not included in this test.

*Comments on the Above Table.*—It must be clearly understood that the above represents merely a summary, and as such slurs many of the details of variation, both between subjects and within a given test for any one subject. For those differences the reader is referred to the more extended discussions and summaries for each test. The present table expresses the general outcome in the way of diagnosis for the various subjects. For example, we have indicated the vocal-motor as present in all tests for all subjects, with the possible exception of P. Yet if we look back through the other lists we find many individual cases where it was absent. However, when we put together all the reports of any subject for any group of tests we find, somewhere in this total, references to vocal-motor or articulatory: a fact which justifies us in saying that all subjects, on occasion. do make use of this imagery-movement complex. A similar statement might be made with regard to other points in the table.

The points which appear from this table in the way of general diagnosis are as follows: (1) No subjects are completely lacking in *vocal-motor* "elements" (imagery or actual movement sensations) or in *visual non-verbal* imagery. (2) The majority of the subjects combine *auditory* imagery with the vocal-motor complex, but three subjects—H., S. and Sun.—are sceptical with regard to the presence of this in any case and are usually very positive as to its absence. (3) Four of the subjects—Ad., H., T. and V.—report a practically complete absence of *visual verbal* imagery in these tests (T. indicating its possible presence in a few cases), while P. reports very little of this, and that very vague, usually. (4) While all subjects report some *visual non-verbal* imagery, there is a very great difference in the vividness and abundance of this, as well as in the accuracy as indicated in the objective results. On the whole, A., C., G., Hs., S. and Sun. report it as extremely abundant and vivid, P. finds it fairly profuse but very lacking in vividness and detail, Ad. uses it in abundance in one test (Pictures), slightly in another (Reading), and none in a third (Memory), while H., T. and V. use a very slight amount, and that very unsatisfactory, in any of the tests.

### 2. Tests for More Accurate Analysis of Types.

The directions which this analysis must take are obviously dictated by the outcome of the preceding tests, as indicated in the above summary. That is, considering the limitations as to scope which we have set up for ourselves, we wish tests which make a special appeal to *visual verbal* imagery, to *auditory verbal* and to *visual of forms and colors.* By such tests we may be able to determine whether a given subject is persistently deficient in a given kind of imagery, or whether its absence in the preliminary tests is due to the fact that it was overshadowed or crowded out by other stronger forms of imagery. All the tests reported in this section have some special bearing along one of these lines, a fact which will be made clear in the course of the discussion.

For the most part we shall follow the order of sequence of tests as given in the list on p. 29. For the sake of compactness, however, we shall combine the account of certain of the distraction experiments with the discussion of the simpler tests.

#### a. TESTS NOT INVOLVING DISTRACTIONS.

#### (1) *Memory Tests.* (See description, p. 29.)

The first two tests of this group, which call for the memorizing of Roman and Arabic numerals and of words pronounced alike but spelled differently, were introduced because of the fact that that they involve materials whose names alone are inadequate to distinguish them from one another. The most obvious and direct way of retaining the differences would seem to be the visual image of the terms as given. Other methods may be used, but as a rule are more clumsy and so are difficult of application in the time given for learning. The tests thus afford a direct appeal for visual imagery.

#### (a) Roman and Arabic Numerals.

In addition to the simple tests with these materials we have included others involving "distraction" of swallowing (see discussion of this, p. 30). As this was designed to reduce the vocal-motor factors, it was thought that it might, by indirect means, intensify any appeal to visual imagery inherent in this test.

*Introspective Evidence.*—The following brief excerpts from the introspections indicate the main characteristics of the imagery used in this memory task. (N. refers to the "normal" cases: *i. e.,* those where no distractions were added. Dr. indicates those carried on while the subject was drinking.)

Ad.

N.—*Aud.-artic.,* with something of a *shock of hesitation* for the Roman numerals, which helped to distinguish. *Vis.* in just one case.

Dr.—*Aud.-artic.* as before. Used *words* for the location of the Romans.

C.

N.—*Aud.-artic.* for first cue. Wrote all numbers first in Arabic, then changed, relying on visual images.

Dr.—As above. Interfered only as distraction of attention.

Hs.

N.—*Aud.-lip-mot.* for numbers, with *vis.* for form of number.

Dr.—Practically no difference, except as distraction. In one case seemed to interfere with artic.

H.

N.—Mainly *artic.* with occasional *vis.* for Roman numerals, also occasional *assocs.*

Dr.—About the same, tho' *artic. somewhat interfered with.* Think it came in between swallows. Rhythm broken up. "If I were sure what *aud.* were like I might think I had some here."

P.

N.—Numbers both *aud.* and *vis.* Also *vis. scheme of location* for Romans.

Dr.—More or less of a distraction—interfered with building numbers into scheme successfully.

### S.

N.—*Vis.-artic.-kinæs.* *Artic.* for all the numbers, *vis.* as determining form, but too profuse to be very satisfactory, *kinæs.* feel for location of numbers. Also *assoc.* connections established.

Dr.—Same except for distraction.

### Sun.

N.—*Vis.-artic* and *relational.* Pronouncing gave cue to the vis. I tried especially to vis. Romans and, accordingly, they stood out on a white background, while the Arabic were lost in a dark background, growing lighter toward the Romans.

Dr.—Interfered mainly as a distraction. Seemed to be able to pronounce just the same.

### T.

N.—*Aud.-artic.* for all, *vis.* for Romans.

Dr.—No interference except distraction of attention. In fact, chief interference seemed to be with the vis., since it required a special act of attention to get this, which drinking seemed to prevent to some degree.

TABLE XV.

*Summary of Introspective Reports.*

| Subject. | Method | Imagery used. | | | | |
|---|---|---|---|---|---|---|
| | | Vis. | Aud. | Voc.-mot. | Form retained by: | Effect of Dr. |
| Ad. | N. | (x) | x | x | Shock. (1 vis.) | |
| | Dr. | | x | x | Words—"Rom.," "Ar." | o. |
| C. | N. | x | x | x | *Vis.* | |
| | Dr. | x | x | x | " | Distraction. |
| Hs. | N. | x | x | x | " | |
| | Dr. | x | x | x | " | " (Slight voc.-mot. disturbance.) |
| H. | N. | (x) | | x | (Vis.) (assoc.) | |
| | Dr. | (x) | ? | x | " " | " (Voc.-mot. disturb.) |
| P. | N. | x | x | | *Vis.* | |
| | Dr. | x | x | | " | " |
| S. | N. | x | | | " | |
| | Dr. | x | | x | " | " (Slight.) |
| Sun. | N. | x | | x | " | |
| | Dr. | x | | x | " | " |
| T. | N. | x | x | x | " | |
| | Dr. | x | x | x | " (less.) | " (Interfered most with vis.) |

*Note:* "x" indicates presence of given imagery.

It appears from the above comments that this test is quite effective in stimulating visual imagery: the purpose for which it was planned. With the exception of Ad. and H., who had almost no visual imagery aroused, and V., who was not given these tests, all the subjects reported dependence upon visual imagery, even P. and T. relying greatly upon it. The presence of auditory or vocal-motor imagery in all cases, in addition to the visual, is entirely in accordance with our earlier results.

The effect of the drinking was chiefly its interference as an attentional distraction, though two subjects report a slight vocal-motor disturbance. In general, however, it appears that whatever the subjects mean here by articulatory or vocal-motor factors can continue during the process of swallowing. In no case did this distraction seem to throw the subject back more upon visual imagery, and in one case (T.) it even interfered with the use of this.

*Quantitative Results.*—If any objective correlations appear from these tests, they should show a disadvantage on the part of the less visual subjects. This might appear in any of several ways, however: (1) There might be a lower degree of absolute accuracy, because of the greater difficulty of the task which they had to perform; (2) There might be more errors in form where the numbers were retained correctly; (3) The vocal-motor distraction—drinking—might cause a greater drop in accuracy for the less visual, by interfering with their vocal-motor substitutes. Our results fail to show consistent correlations in any of these directions, although there are sporadic instances in line with each. For absolute accuracy we find an almost complete lack of correlation, although it may be significant that H., who has showed herself very lacking in visual imagery in this test as well as in others, has the lowest average. With regard to the second point, we find that errors in form where the numbers are correct do occur, but that the less visual subjects are no more involved in these than the highly visual. Accordingly, the value of these errors for diagnosis must be considered negligible, so far as our results indicate. The effect of the attempted vocal-motor distraction was a reduction in accuracy, as indicated by a comparison of averages, for five subjects—Ad., P., S., Sun., T.; a list which shows a combination of strongly visual subjects, slightly visual, and one who used practically no visual in these tests. Moreover, the introspective reports indicate that the drinking interfered, not as a vocal-motor interference, but chiefly because of its effect on the attention, and in one case because it lessened the ability to use visual imagery.

*General Conclusion with Regard to the Value of this Test.*—From the above results we seem justified in considering this test as efficacious in calling forth visual imagery and in furnishing valuable introspective material, but as not yielding objective results which can be readily used for interpretation of imagery processes.

### (b) WORDS PRONOUNCED ALIKE BUT SPELLED DIFFERENTLY.

(See description, p. 29.)

Three normal tests were given, two with the distraction of swallowing, and five with that of whistling, the aim being to supplement the direct appeal for visual imagery by an indirect stimulus. Since the effects of swallowing were similar to those in the preceding test, comments with regard to these are omitted, reference to whistling ("Wh.") being substituted for them.

### Introspective Evidence.

A.

N.—*Vis.* and *aud.-voc.-mot.* with much guessing. More aud.-mot. in reading and more vis. in recall. Said for one: "Felt oscillation. Unable to give self up wholly to either aud.-mot. or vis. Can't get hold of it in learning without vis. imagery. Vis. chiefly in recall."

Wh.—Whistling did not seem to interfere with aud.-mot. "Seemed chiefly to operate to rob of all notion of meanings of words." "Recall perhaps *less visual* than in preceding and a little more aud.-enunciatory."

Ad.

N.—*Aud.-mot.* Some help on locations from *oculo-motor.*

Wh.—As before. Whistling disturbs but doesn't make aud. impossible. *Vis.* in only one case, and *spelling* in only one.

C.

N.—*Aud.-mot.* for position of words. *Vis.* for location of spelling.

Wh.—Same method. Wh. some disturbance, but mainly as distraction, though it seems to interfere some with *aud.* When *aud.* was lost *vis.* did not help.

Hs.

N.—*Aud.-lip.-mot.* for position of words, *vis.* for correct spelling.

Wh.—Same gen. method but *vis.* rather more prominent. Wh. a decided distraction and apparently a special distraction for aud.-lip-mot.

H.

N.—-Mainly *artic.,* but some *vis.* for occasional words. This seemed important in getting correct locations in some cases, though in others it was quite inaccurate.

Wh.—Mainly *artic.,* with occasional *vis.* and some meaning *assocs.* Some *motor* for spatial location.

P.

N.—Mainly *aud.* process. Attempt to keep differences between words in *vis.* terms, but not very successful.

Wh.—Predominant attention given to attempt to get *aud.* series, with which whistling interfered. Some *vis.* but attempt to *rely* on this not successful.

S.

N.—*Vis.-artic.* for each word.

Wh.—Required considerable attention at first, but soon came to make no difference. Distinction made by *vis.,* by *meaning* or by *kinæs.* feel for location.

Sun.

N.—"It seems to be the *pronouncing* that gives the cue. If I can get the 'feel' the *vis.* image will come, but the former seems necessary to give the vis. image." Artificial *assoc.* connections also used.

Wh.—(Not given.)

T.

N.—*Aud.-mot.* and *vis.* also *motions of head and eyes.* (Some vis. for all.)

Wh.—(Humming instead of whistling used by T.) Same way. No special disturbance noted.

V.

N.—*Aud.* for all. Get positions mainly by *spelling,* but time is too short to do this satisfactorily. *Meanings* enter in to some extent, but there is not time to develop these satisfactorily either.

Wh.—Same way. (Whistling quite a frequent accompaniment to her working.)

TABLE XVI.

*Summary of Introspection on Words Pronounced Alike but Spelled Differently.*

| Subject. | | Imagery used. | | | Correct spelling retained by: | Effect of whistling: |
|---|---|---|---|---|---|---|
| | | Vis. | Aud. | Voc.-mot. | | |
| A. | N. | x | x | x | Vis., some meanings. | Interfered with meanings. |
| | Wh. | x | x | x | “ “ “ | Diminished vis. once. |
| Ad. | N. | o | x | x | Oculo.-mot. plus.? | |
| | Wh. | (1) | x | x | Vis. for 1. Sp. for 1. | Disturbs aud. somewhat. |
| C. | N. | x | x | x | *Vis.* | |
| | Wh. | x | x | x | “ | Disturbs aud. somewhat. |
| Hs. | N. | x | x | x | “ | |
| | Wh. | x | x | x | “ | Disturbs aud.-lip.-mot. |
| H. | N. | (x) | | x | (“) | |
| | Wh. | (x) | | x | (“) (assoc.) (kinæs.). | |
| P. | N. | x | | x | *Vis.* | |
| | Wh. | x | x | | “ but unsatisfactory. | Disturbs aud. |
| S. | N. | x | | x | *Vis.* | |
| | Wh. | x | | x | “ meaning, kinæs. | Distraction. |
| Sun. | N. | x | | x | “ assoc. | |
| | Wh. | | | | | |
| T. | N. | x | x | x | “ with eye and head mov'ts. | |
| | Wh. | x | x | x | “ “ “ “ “ “ | o |
| V. | N. | | x | | Spelling meanings. | |
| | Wh. | | x | | “ “ | o |

This test, like the preceding, is evidently successful in calling forth more visual verbal imagery than have many of those used, though the same group of subjects who have been most deficient in this respect in other tests use least of it here (with the exception of T.) : *i. e.,* V. reports none, Ad. only one, H., "occasional," and P. a considerable amount of a sort which he considers unsatisfactory. Other factors are present as before. Whistling seemed to be more successful as a shunt (especially for the aud.) than did the drinking, though it lessened the amount used, rather than entirely eliminating it.

*Quantitative Results.*—The accompanying table gives in detail the quantitative material gained from this test. For our purposes it seemed desirable to give in separate columns the percentages for *words reproduced correctly according to pronunciation regardless of spelling* ("Wd" in Table XVII) and the percentages of *words correct in both pronunciation and spelling* ("Sp." in Table XVII).[16] The difference between these two records is given in still a third column ("Diff").

Several forms of correlation might be anticipated from this test: (1) Since these tests apparently made a special appeal to visual verbal imagery as a means of retaining the correct spelling of the words, it might be expected that the more visual subjects would have the better records for absolute accuracy, as indicated in the "sp." column. On the basis of the averages of the percentages in this column the subjects would appear in the following order according to excellence:

1. S.—82.8
2. T.—76.7
3. Hs.—72.6
4. C.—56.4
5. H.—54.5
6. P.—51.4
7. Ad.—46.4
8. V.—45.4
9. A.—43.4

The first four subjects in the list all use visual verbal imagery as an important form of control in this test, according to their introspections, and all but T. make much use of it under other conditions. On the other hand, the next four all report a general inadequacy of visual verbal imagery, which they could not overcome satisfactorily in this test. So far the correlation is good, though the quantitative difference between C. and H. is very slight. A., however, entirely fails to fit into this grouping, as he has shown himself to be a good visualizer in other tests and he relied upon visual imagery as an aid here. Yet he comes at the end of the list: a fact which illustrates the danger in drawing conclusions from the objective results alone.

(2) The first correlation attempted was based on the absolute accuracy of the results. The second is concerned with the relative accuracy of the *forms* of the words: *i. e.,* the spelling alone. A measure of this is obtained by reference to the differences be-

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[16] A typical instance may show how this distinction was applied. The words of the original series as given are followed by the words—in parentheses—as reproduced. The grading for this would be: "Words," 100 per cent.; "Spelling," 44.4 per cent.

rain (rein) two (two) ere (ere)
too (to) reign (rain) air (air)
rein (reign) to (too) heir (heir)

tween the averages computed for *words and forms* correct and those computed for *words* correct regardless of spelling. The existence of any difference between these is an indication that auditory or motor controls play some part in the learning. It is interesting, therefore, to note that all subjects show some discrepancy between these averages and all report the use of auditory or motor images. It might also be assumed that the slightness of the difference would be an indication of the degree to which visual imagery appeared as a check on the auditory-motor. Arranging our subjects in order according to the size of this difference we have the following list:

1. Hs.— 6.1
2. T.— 7.1
3. H.— 8.1
4. S.—11.0
5. A.—11.1
6. C.—11.2
7. Ad.—16.3
8. V.—20.2
9. P.—24.3

Again the correlation appears roughly. The three subjects who have the largest differences have all reported themselves to be non-visual in this test as in others. On the other hand, of the first six subjects in the list all but one (H.) have used visual imagery for this test, though one (T.) has not employed it as a general rule in other tasks. The case of H. is not difficult to understand, when we refer to the table and find that her record for absolute accuracy was very low, as well as her accuracy for words merely as pronounced. If the lack of visual imagery disturbed her it evidently did so by disrupting the whole process of memorizing rather than by affecting mainly the essentially visual factors in this.

(3) We might also look for a correlation between the interference produced by the auditory-motor distractions and the strength or weakness of the visual imagery as a means of control. Our results are not adequate to show whether such a relationship exists, however, since the distraction experiments came at the end of the series, where the effect of practice might overcome the disturbance occasioned by the distraction.

### (c) WORDS SPELLED ALIKE BUT PRONOUNCED DIFFERENTLY.

For the preliminary series the words were given as described on p. 29. In the later tests, this procedure was modified, since we found that a subject sometimes changed the spelling of the words, when he simply heard them as in the first procedure. Thus, when he heard the two pronunciations of "bass," he might visualize one as "bass" and the other as "base," and thus hold the distinction on a visual basis. This tendency was lessened when the subject was given a typewritten list of the words, with no indication of the pronunciation to be used, to follow as he heard the words read. To improve his opportunity of introspecting on his *imagery* for the words, he was then asked to think through the words once, with the list still before him, and, finally, to read the words aloud from the list. Thus all that he was required to keep was the auditory differentiation between the words.

As before, we shall give first the introspective data, then the objective results, though the latter are less significant because so few subjects are included.

### INTROSPECTIVE EVIDENCE.[17]

A.

5, 9, 10: Aud. of reader's voice, shifting to own voice. Artic. factors as always, though not cognizant of actual movement. Meaning enters in some, but not as much as would be expected Said for 9. "Beautiful aud. images all through, *but was not sure of the order.*" 6: Sounding the vowel knocked out the aud. and the artic. completely during the interval between hearing the series and saying it. Came back in fleeting aud. images with trial pronounciation. 7, 11, 12: Like 6, but rather more of a disturbance. 8: Like preceding tests with distractions, but even greater disturbance.

Ad.

5, 9, 10: Aud.-artic. Strain in throat. Aud. of reader's voice. Some secondary aids. 6: Vowel didn't bother. Process like preceding. 7, 11, 12: For 7 and 11 whistling seemed to have no effect. Artic. strain was noticed. In 12 whistling seemed to bother. Attention was distracted and sound somewhat interfered with.

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[17] In the above account the numbers refer to the number of a given group in the series. Reports on the earlier tests have been omitted for the most part, since there was less certainty expressed with reference to them. Tests 5, 9 and 10 were given with no distractions; 6 with the sounding of a vowel—"a"; 7, 11 and 12 in connection with whistling, and 8 while counting.

## TABLE XVII.

*Percentage of Accuracy in Memorizing Words Spelled Differently, but Pronounced Alike.*

| Subject. | A. | | | Ad. | | | C. | | | Hs. | | | H. | | | P. | | | S. | | | T. | | | V.* | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Im. Control. | A.-M., V. Mean'g. | | | A.-M. (V.). | | | A.-M., V. | | | A.-L.-M., V. | | | Art. (V.). | | | A. (V.). | | | Art., V. | | | A.-M., V. | | | A., Sp., Mean'g. | | |
| | Wd. | Sp. | Diff. | Wd. | Sp. | Diff. | Wd. | Sp. | Diff. | Wd. | Sp. | Diff. | Wd. | Sp. | Diff. | Wd. | Sp. | Diff. | Wd. | Sp. | Diff. | Wd. | Sp. | Diff. | Wd. | Sp. | Diff. |
| Normal. | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| II$_{10}$ | 77.7 | 44.4 | 33.3 | 33.3 | 33.3 | 00.0 | 55.5 | 44.4 | 11.1 | 100.0 | 100.0 | 00.0 | 44.4 | 44.4 | 00.0 | 100.0 | 33.3 | 66.7 | 100.0 | 55.5 | 44.5 | 100.0 | 77.7 | 22.3 | 55.5 | 22.2 | 33.3 |
| 1 | 88.8 | 66.6 | 22.2 | 33.3 | 33.3 | 00.0 | 100.0 | 100.0 | 00.0 | 100.0 | 77.7 | 22.3 | 66.6 | 66.6 | 00.0 | 55.5 | 55.5 | 00.0 | 100 0 | 100.0 | 00.0 | 77.7 | 77.7 | 00.0 | 100.0 | 77.7 | 22.3 |
| 2 | 55.5 | 33.3 | 22.2 | 100.0 | 44.4 | 55.6 | 55.5 | 55.5 | 00.0 | 55.5 | 55.5 | 00.0 | 55.5 | 55.5 | 00.0 | 100 0 | 77.7 | 22.3 | 100 0 | 100.0 | 00.0 | 55.5 | 44.4 | 11.1 | 66.6 | 33.3 | 33.3 |
| Dr. | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 3 | 22.2 | 22.2 | 00.0 | 77.7 | 11.1 | 66.6 | 44.4 | 44.4 | 00.0 | 77.7 | 77.7 | 00.0 | 11.1 | 11.1 | 00.0 | 66.6 | 44.4 | 22.2 | 100 0 | 100.0 | 00.0 | 55 5 | 55.5 | 00.0 | 66 6 | 66.6 | 00.0 |
| 4 | 66.6 | 55.5 | 11.1 | 33.3 | 33.3 | 00.0 | 66.6 | 55.5 | 11.1 | 88 8 | 88.8 | 00.0 | 44.4 | 33.3 | 11.1 | 100.0 | 77.7 | 22.3 | 100 0 | 100.0 | 00.0 | 100.0 | 77.7 | 22.3 | 66.6 | 44.4 | 22.2 |
| Wh. | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 1 | 33.3 | 33.3 | 00.0 | 100.0 | 77.7 | 22.3 | 55 5 | 44.4 | 11.1 | 66.6 | 44.4 | 22.2 | 100.0 | 44.4 | 55.6 | 77.7 | 11.1 | 66.6 | 100.0 | 44.4 | 55.6 | 100.0 | 100.0 | 00.0 | 44.4 | 11.1 | 33.3 |
| 2 | 44.4 | 33.3 | 11.1 | 100.0 | 100.0 | 00.0 | 100.0 | 77.7 | 22.3 | 77.7 | 77.7 | 00.0 | 88.8 | 77.7 | 11.1 | 100.0 | 44.4 | 55.6 | 100.0 | 100.0 | 00.0 | 100.0 | 100.0 | 00.0 | 77.7 | 44.4 | 33.3 |
| 3 | 55.5 | 55.5 | 00.0 | 11.1 | 11.1 | 00.0 | 66.6 | 11.1 | 55.5 | 66.6 | 44.4 | 22.2 | 55.5 | 44.4 | 11.1 | 55.5 | 55.5 | 00.0 | 77.7 | 55.5 | 22.2 | 77.7 | 77.7 | 00.0 | 55.5 | 44.4 | 11.1 |
| 4 | 44.4 | 22.2 | 22.2 | 100.0 | 77.7 | 22.3 | 88.8 | 88.8 | 00.0 | 66.6 | 66.6 | 00.0 | 100.0 | 100.0 | 00.0 | 33.3 | 22.2 | 11.1 | 88.8 | 88.8 | 00.0 | 88.8 | 88.8 | 00.0 | 66.6 | 44.4 | 22.2 |
| 5 | 77.7 | 77.7 | 00.0 | 44.4 | 44.4 | 00.0 | 55.5 | 44.4 | 11.1 | 77.7 | 77.7 | 00.0 | 55.5 | 55 5 | 00.0 | 66.6 | 66.6 | 00.0 | 100.0 | 100.0 | 00.0 | 66.6 | 66.6 | 00.0 | 66.6 | 55.5 | 11.1 |
| 6 | 33.3 | 33.3 | 00.0 | 55.5 | 44.4 | 11.1 | 55.5 | 55.5 | 00.0 | 88.8 | 88.8 | 00.0 | 66.6 | 66.6 | 00.0 | 77.7 | 77.7 | 00.0 | 66.6 | 66.6 | 00.0 | 100.0 | 77 7 | 22.3 | 55.5 | 55.5 | 00.0 |
| Av. | 54.5 | 43.4 | 11.1 | 62.7 | 46.4 | 16.2 | 67.6 | 56 4 | 11.1 | 78.7 | 72.6 | 6.1 | 62.6 | 54.5 | 8.1 | 75.7 | 51.4 | 24.3 | 93.8 | 82.8 | 11.0 | 83.8 | 76.7 | 7.1 | 65.6 | 45.4 | 20.2 |
| M. V. | 17.2 | 15.0 | 10.1 | 29.9 | 20 9 | 18.6 | 15.6 | 17.6 | 11.1 | 11.4 | 14.5 | 8.9 | 19.8 | 17.2 | 10.3 | 18.4 | 18.5 | 21.1 | 8.9 | 20.8 | 16.0 | 15.6 | 11.6 | 9.0 | 9.4 | 13.4 | 10.6 |

*Explanation of table:* The subjects' names are indicated by initials along the upper horizontal line. Below these the striking characteristics of the imagery controls are noted for each, as follows: V., visual images; A., auditory; M., motor; L.-M., lip-motor; Art., articulatory; Sp., shows that words were spelled; Mean'g, that meaning of words was an aid. When a form was used only occasionally or slightly it is put in parentheses. In the vertical column at the left the numbers of the tests are given. Under each subject two columns of percentages are given: Under Wd. are given the percentages of words correctly placed according to their pronunciation, regardless of spelling; under Sp. are the percentages of correct words with correct spelling; under Diff. are the differences between the other two percentages.

* Distraction was omitted with V. for 3 and 4.

C.

5: Aud.-mot. and vis. 6: Same way. "A." did not bother except as general distraction. Think there was maximum of aud. and minimum of mot. 7: Could get aud. all right while whistling. This seemed to make it no harder. 8: Harder. Counting broken up. Think I slipped words in between.

Hs.

5, 9, 10: In 5, tried without much success to use aud. In 9 and 10, did chiefly in aud.-lip-mot. Aud. of reader's voice. Some reference to meaning, but not sure that it helped. 6: Attempt to use aud. image in connection with vis. perception of word. "A" interfered but did not prevent. 7, 11, 12: Decided disturbance, though tune very automatic. Did get some aud.-lip-mot. and tendencies to movement. Tended to stop whistling in order to pronounce. Felt lack of being able to mutter to myself. 8: Great deal of a distraction. Counting broken up. Did get aud., and, I think, lip-mot.

H.

5, 9, 10: Artic. and perhaps two aud. images. Some associations entered in. 6: "A" interfered to some extent. May have had some aud. images. Some associations. 7: "Whistling cuts out artic. fairly well. Think I had aud. for several." For 11 and 12, "Whistling didn't seem to bother much, but there was less artic. Yet got some artic. while actually whistling. Some aud. of reader's voice and some assocs." 8: Similar to 7, but think had some artic.

P.

5, 9, 10: Aud. images. Very definite, vivid and exact images of reader's voice. 6: Essentially a *distraction.* 7, 11, 12. Whistling only a slight disturbance and that purely a matter of attention. Still did in aud. terms. 8: More of a *distraction.* Quite sure that can image both words and counting at once. Aud. image the cue as usual.

S.

5, 9, 10: Vis. and artic., possibly some aud. At least the artic. is more intensive. 6: No difference except that confidence was lessened. 7, 11, 12: Whistling disturbed artic. Couldn't keep up with it but could artic. some. Could tell that it was reader's voice rather than anyone's else. Meaning helped.

### Sun.

(Only prelim. series given to Sun.)

Made certain differences in vis. images to represent differences in sounds: *e. g.*, lengthened space between letters in one case, put in Greek omega in another, etc. She says for one test: "Vis. image most prominent by far for recall, though pronouncing played some part in giving vis. image. In one case I think I had an aud., though perhaps more pronunciatory. It seemed like a fleeting aud. image, however. More like an echo of the reader's voice than anything else."

TABLE XVIII.

*Summary.*

| Subject. | Imagery used. | | | Distinction retained by: | Effect of distraction. |
|---|---|---|---|---|---|
| | Vis. | Aud. | Voc.-mot. | | |
| *A.* N. | | x | x | Aud.-artic. | |
| "a" | | x | x | " " | Interfered with aud.-artic. |
| Wh. | | x | x | " " | " " " " |
| Count'g. | | x | x | " " | " " " " |
| *Ad.* N. | | x | x | Aud.-voc.-mot. | |
| "a" | | x | x | " " " | o |
| Wh. | | x | x | " " " | Distract'n once, aud. disturbance once. |
| Count'g. | | x | x | " " " | Count'g broken up. |
| *C.* N. | x | x | x | " (" "—slight). | |
| "a" | x | x | x | " (" " " ). | Very slight distract'n. |
| Wh. | x | x | x | " (" " " ). | o |
| Count'g. | x | (x) | x | " (" " " ). | Harder. Count'g broken up. |
| *Hs.* N. | | x | x | ("—tried to use). Lip.-mot. | |
| "a" | x | (x) | x | ("—tried to use). Lip.-mot. | Interfered somewhat with aud. |
| Wh. | | x | x | " Lip.-mot. | Interfered somewhat with aud. |
| Count'g. | | x | x | " (Lip.-mot.?) | Distr. Count'g broken up. |
| *H.* N. | | ? | x | Artic. | |
| "a" | | (x) | x | " (and perhaps aud.). | Artic. somewhat disturbed. |
| Wh. | | x | x | (") and aud. Assocs. | " " " |
| Count'g. | | x | (x) | | " " " |
| *P.* N. | | x | | Aud. | |
| "a" | | x | | " | Distraction. |
| Wh. | | x | | " | " |
| Count'g. | | x | | " | " (Can image both.) |
| *S.* N. | x | | x | Artic. | |
| "a" | x | | x | " | Lessened confidence. |
| Wh. | x | ? | x | " (and aud.?). | Bothered artic. |
| Count'g. | x | ? | x | " " " | " " |
| *Sun.* (Prelim.) | x | ? | x | Vis. diff. (aud.?). | |

A comparison of these tables with those on p. 101 and p. 105 shows that the present test calls forth less visual imagery and more auditory than the two preceding tests. All but the subjects who have been dubious with regard to the presence of auditory images from the beginning (H., S. and Sun.) report these as constantly present, though Hs. notes some difficulty in getting them. H., S. and Sun. report it as possibly present. The distractions used are effective in several cases in decreasing the amount of articulatory imagery and almost forcing the subject to depend on auditory, and in several cases the auditory imagery was disturbed.

*Quantitative Results.*—It might be expected that, in these tests, the advantage would be with those subjects who use *auditory* imagery with readiness, rather than with those who are mainly dependent upon vocal-motor. By reference to the preceding pages it will be seen that the latter are H., S. and Sun., and that Hs. reports difficulty in connection with the auditory imagery, especially in the first series. If these tests as a group operate unfavorably towards the non-auditory subjects, this fact should appear objectively by a lower average of accuracy on their part for the series. The following are the averages, together with the mean variations, for the six subjects who were given all eight tests: A.—73.6 ± 18.7, Ad.—76.3 ± 13.2, Hs.—74.9 ± 14.6, H.—79.1 ± 18.1, P.—81.9 ± 9.1, S.—72.1 ± 9.7. It is evident, first, that the mean variations are very large, showing that a much larger number of tests would have to be used, before we could feel that the averages were very significant. The changes in conditions, which were introduced for the introspective material which they might afford were doubtless partially responsible for the extent of these variations. The averages themselves do not prove very illuminating. Instead of H., S. and possibly Hs. being at the foot of the list and separated from the other three subjects by a large difference, they are scattered through the list and the differences from subject to subject are slight. It might be anticipated that such a discrepancy between the subjects would be more apt to appear in the records for the five tests where distractions were added, if these distractions are more of a handicap to the subjects who depend most upon vocal-motor factors. The averages do not show this result, however. They are as follows: A.—71.1 ± 21.3, Ad.—66.6 ± 13.3, Hs.—68.8 ± 12.6, H.—82.2 ± 20.8, P.—75.5 ± 3.5, S.—66.6 ± 8.9. The low records for A. and Ad. and the high record for H. are quite anomalous, so far as any such interpretation is concerned. H. even shows a higher average for the tests with distractions than for those without.

While the failure to find a correlation between the quantitative results and the character of the imagery used does not prove the impossibility of an objective use of these tests, if the number of tests and of subjects be sufficiently increased, they do serve to confirm us in the opinion that the method is of value chiefly for the introspection which it stimulates. There is a difficulty in the way of increasing the number of the tests, due to the relative scarcity of these materials. It is, of course, possible to use the same words in several different combinations, but that duplication itself introduces a change in conditions. As the results stand, it must be admitted that they do not show a serious handicap for the subjects who use vocal-motor controls where the others add to these auditory imagery.

### (2) *Matching and Sorting Tones and Shades of Colors.*

(See Description, p. 29-30.)

These tests were designed for purposes of both diagnosis and training of deficient color imagery. We shall discuss them briefly from the standpoint of the former use.

*Introspective Records.* In general, we may say that all the subjects who showed any great readiness in the use of color imagery in our earlier tests, tended to rely upon it here to a great degree. This does not mean that they necessarily used it throughout the operation of matching or sorting. The selection might be made largely as a kind of a sensory recognition, involving no reference to imagery. But all the above subjects fell back upon visual imagery to some extent, either in the moment just before beginning the sorting, or when the first color was being placed, or when they were dubious as to the location of some particular card, etc. At such points visual imagery could be decidedly helpful.

Our attention was directed especially to those subjects who reported least "concrete" visual imagery in the preceding tests and the greatest tendency to name materials (Ad., H., T., V.). In these tests the same tendency persisted, but its inadequacy was quickly forced upon the subject. Such comments as the following indicate the recognition of the faultiness of this technique:

Ad.—"Said, 'nice light green,' but the trouble was that there were other nice light greens in the series." H.—"When looking at the standard color, articulated the word 'dark orange,' and repeated this when shown the series, but at once discovered that there were several darker oranges and discarded the verbal cue entirely, making the choice by means of the visual image," etc. The latter comment also indicates the change which sometimes took place: *i. e.,* a development of visual imagery of the color to meet the difficulty. Another type of change which was frequently mentioned was an increase in the accuracy of the descriptive terms applied to the colors. All of the subjects showed some of this tendency. H., T. and V. reported also some dependence on visual imagery for the final decision. Ad. reported practically none of this in any of the later series, though it appeared in a very few of the preliminary tests.

In general, this test, like that with the pictures, seems quite successful in calling out visual imagery where this can be used, though this failed with Ad., while the other (*i. e.,* the pictures), succeeded.

*Objective Results.* The objective results are not presented, because, for reasons quite extrinsic to these tests as such, the conditions under which they were performed were too variable to justify us in using the quantitative materials: *e. g.,* for several of our subjects, long time intervals were of necessity allowed to pass between the early and the later tests of the series, so that a comparison between the various subjects is not justified. Certain indications of our results have suggested, however, that a set of these tests, carried out under more carefully controlled conditions, might yield confirmatory evidence of considerable value.

### b. TESTS INVOLVING DISTRACTIONS.

We shall not discuss in detail the implications of these tests. The issues have already been defined in our historical account (see p. 10 ff), and the critical attitude assumed by Segal and Sybel has been mentioned. Before proceeding to our own results, however, reference should be made to Miss Downey's use of similar distractions in her investigation of writing controls (37).[18]. This is cited here, instead of in the historical section because it is so closely related to our work, and thereby makes it possible to dispense with a report of the diagnostic results gained by this method when applied in the usual way: *i. e.,* in conjunction with any form of task which may be under consideration.

Two differences in the use made of these tests by Miss Downey and by the author should be noted. In the first place, the primary aim of Miss Downey appears to be the reduction of the writing process to an automatism by actual distraction of attention to another performance. In our work, on the other hand, the attentional distraction is always disturbing, since it tends to obscure the issue of imagery conflicts. This difference in interest leads to a still further difference in method. Miss Downey uses for the main process an habitual performance, but for the distraction something which calls for more or less attention. Our arrangement has been exactly the reverse of this: *i. e.,* the main process has been made as unhabitual and problematical as possible, and the distractions used have been largely habitual in character, in order that the attentional disturbance might be slight. In the light of these differences in mode of approach, it is all the more striking that we should have arrived at conclusions so similar. The following statements of her results should be noted for their bearing on the question of diagnostic value.

"It is evident that success in meeting the conditions of the test does not depend, except to a very slight extent, upon versatility in the use of various imagery processes nor upon skill in 'shunting' these processes, although such 'shunting' occurs at times. . . . . General habits of attention were much more potent in facilitating or retarding operations. . . . . Still more influential, however, is the tendency to focus by way of certain processes, so that success is more often achieved *by a*

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[18] For a full account of this portion of Miss Downey's work see *loc. cit.* (37, 54-126). Pages 54-56 are especially valuable for general discussion of the significance of these tests with reference to both attention and imagery. Pages 98-100 present conclusions with regard to the effect of the given distractions on imagery.

*synchronization or oscillatory conflict of two similar processes* having high attentional value, *than by 'shunting' so as to avoid imagery conflict. In this way B drives abreast two auditory or vocal processes, and S, A and D two visual processes.'"* [Italics ours.] P. 98-99.

"Any particular distraction either (1) introduced conflict of imagery and so threw a particular control process into the foreground; or (2) caused a 'shunting' of the control and so tested the various possible 'controls' of the subject tested; or (3) issued in actual distraction of attention from writing for a longer or shorter interval, so that writing approached automatism." P. 54.

These statements are thoroughly in accord with the results obtained by us in a great variety of applications of these distractions, as described on p. 30. To the three effects above noted, we might add a fourth: *viz.,* the absence of any observable interference, a result which was more apt to appear in our work than in Miss Downey's. In fact, we were constantly in search of a distraction which might prove a mean between the two extremes of too great attentional disturbance and too little. A "distracting" process which reaches the latter extreme is ineffective from the standpoint of imagery conflict. But even if this difficulty be partially overcome, the situation is not free from ambiguity, for Miss Downey's statements show that either of two opposite effects may appear: *i. e.,* either a weakening or an intensification of the conflicting imagery. Evidently, then, the principle cited on p. 10 as the basis of the objective application of these tests: *i. e.,* the assumption that sensory activities or imagery processes of any sort interfere with the simultaneous arousal of imagery of the same kind—has been proved not universally valid, and therefore not a safe basis for diagnosis. Miss Downey's contributions with regard to the use of this method are, therefore, in line with the conclusions of Segal and Sybel, as well as those of the author. That is, at times the principle of interference and consequent "shunting" of imagery operates perfectly, and the result appears in the diminution of efficiency, affording an objective indication of imagery normally used. But at other times, the imagery which should be discarded in accordance with this principle continues to be used with no loss in effectiveness, and occasionally with even an enhancement of value. Like most of the other so-called objective tests, these are merely confirmatory at best, except as the introspective material afforded proves serviceable.

The conclusions, based on our own results, may be made more specific with reference to the relative values of the various forms of distractions used, and also in regard to certain special applications which we made of them. It may be well to note, also, that many of the tests belonging to this group were introduced for their bearing on the problem of "training," and not primarily for their diagnostic value. They will be more fully discussed when the report is made on that aspect of the work.

*Relative Value of Distractions: Visual.*[19] Of all the distractions, these were the least successful for the analysis of imagery. It seemed impossible to strike even an approximate mean between the two extremes of overwhelming absorption of attention on the one hand, and complete lack of disturbance on the other. The two distractions used by us—tracing or copying a pattern and sorting colors—were capable of varying degrees of difficulty, but proved always either so easy that they offered no interference, or so hard that they interfered with the simultaneous performance of any other mental act. S. is the only subject who showed any evidence of even a confirmatory value of these distractions. They proved excessively disturbing to him in whatever combination they appeared, completely disrupting even such a task as listening to the reading of a passage. Though this effect occasionally took the form, according to S.'s introspection, of interference with the visual imagery which would normally have appeared, it was equally likely to evince itself in a breakdown of the articulatory processes.

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[19] By "visual" distractions we mean those which might be expected to conflict with visual imagery alone. Accordingly we have not included under this head such tasks as mental reading, since this involves for most persons a constant accompaniment of an auditory or articulatory sort, so that the distraction is not merely "visual," but "visual-auditory," "visual-articulatory," or "visual-auditory-articulatory." This usage is slightly different from that of Miss Downey, who applies the term to any distraction which is presented visually.

*Articulatory or Vocal-Motor Distractions.* We have included in this group simply those which might be supposed to embarrass the articulatory without effect on the auditory elements. It seemed that these should be especially effective in cases where overt movements made up a part of the normal complex. The first two methods—pressing the tongue against the upper gums, and exhaling slowly—proved practically ineffective, except as introducing a certain amount of discomfort and inconvenience, which affected all subjects regardless of type. The third method—swallowing—was introduced, in the attempt to prevent movements or images of movements of the back of the mouth and throat, which were reported as important by certain subjects. In general, however, it proved ineffective as a disturbance after the first newness and consequent demand on the attention had worn off. Reference will be made to certain special uses of this test in connection with the discussion of those of the next group.

*Auditory and Articulatory Distractions.*[20] Under this head we have included those methods which involved either actual auditory stimulation or the use of auditory imagery, and, for the most part, overt articulatory movements, though articulatory *imagery* was perhaps accepted as a substitute in a few cases (silent counting, etc.). All of those here cited proved successful to varying degrees, under certain conditions and with some subjects. These are the methods to which we referred in our general discussion of distraction methods, and are very similar to those used by Miss Downey. It is evident that these, when effective, may prove simply auditory disturbances, simply articulatory, or both, depending on the kind of imagery normally used by the subject. The first method mentioned—continuous sounding of a letter—practically belongs with the preceding group of articulatory distractions, since the auditory stimulus was so monotonous that it appeared to introduce no conflict with auditory imagery. The other methods occasionally did cause such a conflict.

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[20] Pure auditory distractions were not attempted by us, since they had not proved satisfactory when used by other investigators. The sounding of a metronome was the form most often used, but Meumann reports this as unsuccessful, since the subjects were able to disregard it entirely after a little practice. More satisfactory methods might have been discovered, but the combination auditory-articulatory methods seemed to meet the needs of the situation.

*Special Applications of Distraction Tests.* A more specific account of certain applications of these tests has been promised. These represent a more definite testing of the principle underlying the use of distractions, and were elaborated with special reference to their use in the training series. In the following statement we shall illustrate our points by means of the auditory and articulatory distractions, though the same principles were used in connection with the visual distractions. Since the results of the latter tests were all (with the one exception—S.—noted above) in line with our earlier decision to the effect that we had no adequate visual distractions, the facts are not presented in detail.

If the principle which forms the basis of the distraction methods is correct, two corollaries should follow: (1) If there are tests which normally demand the use of a given form of imagery (X) by all subjects, a "distraction" involving the use of X imagery or sensory material will either break up the work entirely or force the employment of another form of imagery, presumably less adequate for the situation; (2) if tests can be found which may be performed in terms of either X or Y imagery, or both, but not apparently without one of these, a "distraction" involving the use of X material should force the use of Y imagery in the case of all subjects who are not completely deficient in this form. As a test case, it would be desirable to try this principle with tasks, for the performance of which the majority of subjects had relied largely upon Y imagery, though a few had used little or none of this. If the principle works under such conditions, we should have a method for stimulating and possibly training defective imagery.

Test of the first corollary was made as follows. Our earlier results have shown that practically all the tests called out a certain amount of imagery belonging to the auditory-vocal-motor complex from all the subjects. In some tests this was felt to be unessential and superfluous, while in others the subjects all insisted that they could not perform the task without some part of this complex. Two marked instances of the latter were the tests in which the subjects made lists of rhyming words and those in which they memorized words spelled alike but pronounced differently. The former were given in combination with the distractions of swallowing, continuous sounding of a letter (as a-, e-, o-, etc.), counting and saying the alphabet. In no case was the performance of the test in terms of the subject's normal imagery made impossible, though there was a slight interference in a few cases, especially with the two last-mentioned distractions, where the subjects sometimes resorted to the expedient of slipping the words in between the numbers or the letters. The objective results showed that the work could be done with no marked diminution in efficiency when combined with distractions.

Both the introspections and the objective reports on the memorizing tests with words spelled alike but pronounced differently have been given (see pp. 107-112). The original task to be performed was more difficult than the preceding, and the effect of the distractions was accordingly more marked. Some interference was noted in almost every case, though this was very slight with the first distraction—continuous sounding of a letter. Extreme difficulty was sometimes felt with the other two distractions—whistling and counting—especially with the latter. (In this case the difficulty was sometimes so great as to lead to a breakdown in the counting.) On the whole, the articulatory processes were much more seriously affected than the auditory: a fact which justifies partially the use which has often been made of these tests as simply articulatory disturbances, with no reference to the possible auditory interference. In spite of this positive evidence in favor of the "distraction principle," certain emphatic negative statements were made. Note, for example, the following statements: C.—"Whistling seemed to make it no harder, except for the effort of keeping it going. Could get aud. imagery all right." P.—"No real conflict between forms of imagery. Still did it in aud. terms." S.—"Whistling disturbed articulatory, but I could still articulate somewhat."

We must conclude from the above that the absolute validity of corollary I has been disproven, though the principle involved is sometimes operative. The proper degree of *attentional* conflict must apparently be secured before any *imagery* conflict appears. That this would prove to be the case should have been anticipated from the fact of common observation, that the average person secures visual images while in the presence of visual stimuli—*i. e.,* with eyes open—and auditory images while affected by auditory stimuli, provided in both cases his attention is not drawn to the given stimuli.

The second corollary was tested with reference to two different applications, both of which we hoped to utilize for purposes of training. For the first of these we selected tests which had proved effective in stimulating visual imagery with all but a few subjects, who had used little or none, performing the task usually by means of some form of auditory-vocal-motor imagery. These tests were then repeated with auditory-vocal-motor distractions in order to determine whether the given subjects would be forced to use visual imagery or fail in their work. The tests used to stimulate visual imagery were spelling backwards, memorizing Roman and Arabic numerals or words pronounced alike but spelled differently, and describing pictures. The subjects who used a relatively slight amount of visual imagery in these were Ad., H., P. (?), T., V. (The deficiency of visual imagery was least marked in the picture test, and did not even exist there for Ad.) The distractions used in connection with spelling backwards were swallowing, counting and saying the alphabet. The first of these was effective simply as a general disturbance and as an interference with the overt articulation used by many subjects. It never forced the visual into greater prominence. The other distractions were both very serious disturbances, sometimes making the spelling practically impossible. In a few cases they did serve to stimulate visual images, but, on the other hand, they seemed at times to reduce this in the case of subjects who normally used it.

The distractions of swallowing and whistling were used with the memorizing tests, with results which have been described on pp. 100-112. The swallowing proved no disturbance for the auditory-articulatory, and the whistling only a slight interference with the auditory imagery, together with a considerable attentional effect. In no case did they seem to increase the tendency to use visual imagery, and in a few cases, where this was naturally weak, they actually diminished it. The objective results show a reduction of efficiency in many cases, but this tendency is obscured by the counter-effect of practice.

Since the tests with pictures were introduced wholly for the training series, certain changes were made in the method of presentation, which served as at least partial compensation for the effect of the distractions. This makes it impossible to determine whether the distractions have occasioned any greater dependence on visual imagery. On the negative side, however, it appears that there is little, if any, interference with the use of verbal imagery. The general disturbance is much less in the case of whistling than in that of the recitation of the verse.

From this group of tests as a whole, there appears no great tendency to employ visual imagery as a "shunt" system, even when the auditory-articulatory forms are embarrassed. In other words, it is not a very promising method for purposes of training.

The second group of tests for corollary 2 are identical with those used for corollary 1, though the point of approach is different. We are concerned here with the question whether subjects who claim to be deficient in auditory imagery will be forced to rely upon it, if vocal-motor distractions are used in connection with tests which demand some form of auditory-vocal-motor imagery. Of the distractions used, swallowing is the only one which includes practically no auditory factors. The assumption that these tests might force dependence upon auditory imagery may, therefore, seem unreasonable. Yet we have seen that the given distractions did interfere with the articulatory processes more seriously than with the auditory in the case of those subjects who used both. Moreover, it has been a very common belief that, whatever might be the possibility of driving abreast two auditory or two visual processes, two articulatory processes could not be carried on synchronously. Perhaps this is partially due to the doubt often expressed as to the existence of articulatory *imagery* distinct from actual movements. That swallowing, sounding a vowel, counting, etc., must interfere with the actual articulation of rhyming words seems obvious.

This problem appealed to us as especially important, since the subjects who claimed to perform, by means of articulatory processes alone, tasks in which the majority of subjects relied upon auditory imagery, have been among our most puzzling cases. (That this has also been a storm center historically is evidenced by the Stricker-Egger-Dodge controversy, mentioned on p. 16.) This much, at least, we may expect to gather from these tests: proof either that the introspection of these subjects relative to the absence of auditory imagery is untrustworthy, or that the present diagnostic method is unreliable.

Without reviewing the material in detail, we may call attention to the following facts: There appears to be a certain tendency of these distractions to operate as we have suggested and stimulate auditory imagery through interference with articulatory. In the tests requiring memorizing of words spelled alike but pronounced differently, even H., S. and Sun. reported occasional auditory images or at least expressed themselves as doubtful as to whether certain images were auditory or not. Yet in certain crucial tests this effect did not appear, and the articulatory processes continued in full or merely diminished vigor. In the tests requiring the formation of lists of words grouped according to sound (rhyming words), these subjects—H., S. and Sun.—claimed that discriminative articulatory images and movements appeared, even while they were swallowing, saying "a," etc. Moreover, they insisted that, in many cases, this was their only way of distinguishing between the sounds and thus deciding the grouping.

The possibilities which seem to face us on the basis of these results are: (1) If the introspective reports are correct, the articulatory tendencies—whether as actual movement or as imagery—are very persistent in these subjects, and cannot be eliminated or even greatly reduced by such distractions as we have used; in other words, by any methods not involving considerable distraction of attention, which may prove equally disturbing to other forms of imagery. (2) The subjects' introspection may be incorrect. There may be strain about the throat, tongue, etc., but the real discrimination may be in auditory imagery, not recognized as such by the subjects. The author's own introspection on this performance would lead her to favor the latter interpretation of the situation, but this means a flat challenge of these subjects' introspection, which has been given with great assurance and under varying conditions. The question must, therefore, be left open.

The following conclusion may be drawn from the above dilemma, however: If the introspection of these subjects is correct, no objective method at our disposal can be *relied upon* to determine whether auditory imagery is present in a given verbal complex, since the articulatory processes seem capable of all the refinement and the persistence under adverse conditions that has usually been considered more characteristic of auditory images.

### C. SUMMARY OF DIAGNOSTIC RESULTS OF TESTS FOR MORE ACCURATE ANALYSIS.

Since these tests have been directed toward the solution of certain particular problems, we may summarize the outcome with reference to those questions. General information along the lines of that gained by the earlier tests is not repeated at this point. We shall present here simply additional information secured by these tests relative to the visual verbal, the auditory verbal and the concrete visual imagery of these subjects.

#### (1) *Visual Verbal Imagery.*

The preliminary tests have indicated, as Meumann and others have claimed, that visual verbal imagery is a much less common form than auditory-vocal-motor verbal. Not only does the average subject use it less, but certain subjects—Ad., H., T., V.—have appeared to be almost entirely deficient in it. Before accepting the deficiency of these subjects, however, and proceeding to the attempt at training in this direction, it seemed important to determine whether other tests might not precipitate this form: *i. e.,* to determine whether the earlier tests were adequate to discover its presence. In these later tests we have tried both direct and indirect appeals, the former consisting of the use of situations which seemed to place a positive premium on visual imagery, the latter involving the introduction of distractions planned to eliminate the auditory-vocal-motor forms.

The results cited have shown that the two memory tests designed for the sake of a positive appeal to visual imagery —(1) combinations of Roman and Arabic numerals and (2) words differing in appearance but not in sound—were successful to a considerable extent in arousing visual verbal imagery. All the subjects who used it slightly in other tests depended largely upon it here. Of the four most deficient subjects, Ad. and V.[21] were least affected by the demand for visual, persisting in their report of practically none. H. used only a slight amount but apparently derived help therefrom. T. reported it as present in abundance and important for learning.

The indirect method of attempting to throw the visual verbal into prominence by interfering with the auditory-vocal-motor forms by means of distractions was less effective. With the subjects who made a moderate use of visual verbal in the performance of the given tasks, the addition of the distractions did not seem to increase the amount of this. The other subjects all reported sporadic cases where visual imagery appeared to be precipitated by the use of these distractions in connection with tests which themselves formed a positive appeal for visual. These were, however, only occasional instances, which diminished in number as the methods of distraction became more familiar. In certain cases, on the other hand, the reverse effect appeared, the disturbance actually resulting in a diminution of the visual imagery, which has previously been used with difficulty.

The objective results of the tests representing the direct appeal furnish frequently a confirmation of the introspective statements and may, therefore, be considered of some value for purposes of diagnosis. No such significance seems to attach to the results of the indirect method, however.

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[21] The Roman and Arabic series was omitted with V.

(2) *Auditory Verbal Imagery.*

Another individual peculiarity which appeared in the course of the earlier experiments was the lack of auditory imagery on the part of three subjects—H., S. and Sun. All of the other subjects had reported that auditory imagery was an essential part of the verbal complex, and most of them asserted that it was the most important element. In the present testing of the correctness of the original diagnosis of H., S. and Sun. two questions were considered fundamental: (1) Is this diagnosis correct or is the insistence upon absence of auditory imagery due to faulty introspection? (2) Provided the introspection is correct, is it still possible by the use of suitable tests to force these subjects to use auditory imagery, even prior to any training? The two problems were approached by the same methods, which involved the attempt to force dependence upon auditory factors or to prevent the use of vocal-motor aids.

The most crucial test which was applied with reference to the first point was the combination of an articulatory distraction with a test which apparently demanded a recognition of sound differences. As has been indicated, the introspective accounts of the three subjects in question confirmed the earlier statements, in that they still asserted that most of the work was done without auditory imagery, but with dependence upon vocal-motor imagery or movements. The issue that confronts us at this point has been defined (p. 122). It is an issue between introspection and the implications of the objective results. On the question of fact, therefore, as to whether the subjects' introspections are correct we have made no appreciable progress by the present group of tests, beyond the introduction of a slight degree of uncertainty as to the validity of their reports. The chief gain accruing from these tests is the fact that the issue is raised under genuinely critical conditions, a point of significance with reference to the problem of training.

Assuming the correctness of the original reports, we can only say with regard to the second question that these tests have aroused in these deficient subjects slightly more auditory imagery than the preliminary series. (They stimulate a very large amount of auditory imagery in those subjects who command it even fairly well.) However, the increase for H., S. and Sun. is far from convincing and leaves them still markedly deficient in this form of imagery.

### (3) *Visual Concrete (non-verbal) Imagery.*

The earlier tests as a whole had shown that three subjects—H., T. and V.—were very deficient, though not utterly lacking, in visual concrete imagery; that one—Ad.—was quite erratic in his use of this, sometimes using a considerable amount and sometimes none at all; that another—P.—found it fairly frequent, but lacking in clearness and definiteness; while the rest all showed considerable proficiency in the summoning of this form. Even with the latter group, however, not all the tests which were designed to appeal to visual concrete imagery succeeded in equal measure. Therefore, failure to report any such imagery for certain of the tests need not indicate that one's visualizing capacity is below the average. The tests of the preliminary series on which we relied for information as to the relative capacity of different individuals were certain of the descriptive passages, certain of the problems and the tests with pictures. In the present group our only additions were the introduction of distractions with the last-mentioned tests and the new experiments in matching and sorting colors.

We have stated that the former—distractions with pictures—furnished no information of value beyond that given by the simple tests with pictures. The latter test was directed toward a better analysis of color imagery, with special reference to the accuracy, as well as the abundance, of such imagery. It proved, as the tests with pictures had clearly shown, that all of these subjects had some capacity for summoning color images. Moreover, the same subjects seemed more or less deficient as in the preliminary tests: *i. e.,* Ad., H., T. and V. These differed from the picture tests, however, in that Ad., who had summoned a considerable amount of satisfactory visual imagery for the latter, was most deficient here, not even attempting to use it except in a very few cases. On the other hand, T. and V. relied to a certain extent on visual imagery, the latter commenting on the fact that the geometrical boundaries of the color were often lost when the color-tone remained correct, but a mere blur or wash of color. P. reported a similar appearance at times, which is quite in line with his earlier reports of the vagueness and indefiniteness of many of his visual images. These results indicate that more accurate information as to the character of the visual deficiency might be gained by the addition of tests involving slight differences in form, just as these involved slight differences in color-tone: a suggestion which we were not able to carry out within the limits of the present experimentation.

On the whole, it appears that this test has added some valuable information with regard to the color imagery of our subjects. It is evident, however, that such a test as this cannot be accepted as our only measure of the capacity of the subject for such imagery, since certain other tests had stimulated more for at least two of the subjects—Ad. and H.—though apparently less for T. and V. The reason for this discrepancy is not clear, but the fact emphasizes the necessity for the use of a variety of tests before drawing any conclusions with regard to the relative capacity of the various subjects for use of a given form of imagery.

## IV. GENERAL CONCLUSIONS.

### A. INDIVIDUAL DIFFERENCES IN IMAGERY EQUIPMENT.

1. *Marked differences in the character of the imagery used by the various subjects do exist.* Certain individuals can and do summon profuse, distinct, detailed, stable and accurate imagery belonging to a given sensory field, while others describe themselves as either quite unable to secure any imagery of the given kind, or as making little use of it, or finding it unsatisfactory in some respect when it appears.

2. These differences cannot be formulated as simply a matter of better or worse imagery of a given sort, since it appears that the various characteristics which determine the rating of a subject's imagery as poor, fair, good, etc., are independent variables to some extent.[1] This statement is not invalidated by the fact that there seems to be a considerable degree of cohesion between these characteristics in the majority of cases, in that the best visual or auditory subjects, for example, report not only more profuse but more vivid, accurate, stable, detailed imagery, while the poorest find their imagery both scant in amount and poor in all these respects. But between these extremes are exceptions to be reckoned with. Perhaps the most striking of these are represented by the comments of S. and P. with reference to their visual imagery, S. finding it usually exceedingly profuse and vivid but often lacking in accuracy, and P. observing a considerable amount of vague and ill-defined imagery. The author's own concrete auditory imagery furnishes also a case in point, since memory imagery for tunes appears with great frequency, but is usually characterized by extreme inaccuracy.

In the author's opinion all such discrepancies are important in any determination of the rating of a given subject's imagery.

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[1] See discussion on pp. 18-20.

She therefore dissents both from the views of those writers who wish to establish the vividness or the abundance of a given kind of imagery as the sole aspect to be considered in the determination of "type," and from that of Segal, who holds that neither of these is relevant to the question of types.[2] It is difficult to see the necessity or desirability of eliminating from consideration such obvious and significant attributes of an individual's imagery as these. We are ready to accept as factors of weight in any decision with reference to type, whatever characteristics make one particular kind of imagery better and more available for use.

3. As obvious as the variations between individuals in the characteristics of images were the changes which occurred in the imagery of a given subject with changes in the character of the tests. To some extent these followed the lines explained by Segal,[3] according to whom the clue to such changes is to be found in the classification of tasks as those which may be performed by any of three forms of imagery, by two only, or by one only. Obviously, changes are to be expected in passing from one to another of these groups, if the exact character of the appeal is varied sufficiently. Our results would lead us to accept this principle of variation as operative, with the qualification that symbolic imagery, especially verbal, is often effective in meeting the demands of a given form of test and neutralizing its special appeal.

Moreover, Segal's principle must be accepted as merely a partial, rather than an exhaustive, explanation of the shifts in imagery. He lays especial stress upon the kind of imagery used in tests which might be performed by the use of any of three forms of imagery as the real index of "type," implying that this would usually be constant for a given subject. We have not found this to be the case, however. Many shifts appeared in the kinds of imagery used in tests, all of which offered an option between three or more varieties. Some of these shifts could be explained, while others seemed more or less erratic. For example, we should not have predicted that the tests with pictures would stimulate so much more concrete visual imagery than the memory tests with simple colors and forms. Angell (5) and Müller (78) have both commented on these "accidental" shifts, the latter noting that a change in imagery sometimes occurs with so slight a variation as the change from immediate to delayed recall.

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[2] See p. 20.

[3] See p. 20.

4. We have been forced to conclude, therefore, that the individual differences in imagery are too complex to be stated adequately in terms of differences in "type," unless this "type" is carefully explained for each individual case. It would be a difficult task to pick visual, auditory or motor types from among our subjects, although it is easy to discover certain ones who make much use of visual imagery, of auditory, of motor, and others who use little or none of a given form. But we have found that all of our subjects use with readiness at least two forms (H. offering a possible exception), and that most of them use more. We should, therefore, have to designate them all as "mixed types": an unfortunate outcome, since it tends to lessen the appreciation of the real differences which exist.

Segal's criticism (96) of the termed "mixed" seems well taken, also: *i. e.,* that most writers use it indiscriminately to cover cases where different forms are used at the same time and those where they are used on different occasions. It is, of course, possible to make the term "mixed" more specific by the addition of further descriptive phrases: a possibility which is in line with our own positive suggestions with regard to ways of formulating these differences.

We have no panacea to offer in the line of single definitive terms. Our solution of the problem consists rather in recognizing the complexity of the imagery situation and abandoning the attempt to express these individual differences by any few catch phrases. An adequate statement of an individual's "imagery type" would involve an account of the kinds of imagery used in various representative situations, with an estimate of their relative importance and a discussion of the characteristics of such imagery under the varying conditions.

We do not consider, however, that such a complete characterization of a subject would be essential in every discussion of imagery. Where the interest is centered on one given form, as for example, the auditory, it may be adequate, for that investigation, to refer to a subject as strongly, moderately or slightly auditory, or non-auditory, provided that it is understood that this designation is significant only as an answer to questions bearing on his auditory capacity, but is not a comprehensive formulation of his type. Again, it is possible to survey the imagery used by a subject for a given type of procedure—as, for example, reading, acquiring motor control, memorizing, etc.—and to refer to him *under such conditions* as predominantly visual, auditory, auditory-motor, etc. This characterization need not be misleading, providing there is no attempt to carry over this description to other forms of behaviour which have not been experimentally tested.

In spite of our belief that an individual's type can be adequately indicated only by an extended statement, we recognize that it is sometimes desirable to group subjects in accordance with certain of their more striking characteristics. For our own thinking we have found it convenient to classify our subjects into the following groups[4]:

(1) The more versatile subjects, who seem to use visual, auditory and vocal-motor forms with perfect ease, changing from one to another with change in the material, or using all forms in handling one kind of material. In the normal distribution of their imagery it seems to be true that visual concrete and auditory-vocal-motor are their more common forms, but they have shown themselves to be perfectly able to summon visual verbal and auditory concrete imagery when an appeal was made to these forms. (This designation of the given subjects as versatile does not indicate that that would be equally proficient in the use of such forms as tactual, taste and smell imagery. Those forms are disregarded in this grouping, because our very limited consideration of them makes it impossible for us to judge of the

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[4] It is evident that the following classification is partially dictated by our interest in the problem of training. The first main group would offer few incentives for training along the directions considered here, while the second group would furnish the material of which we were in search.

relative capacity of our subjects for their use.) Among our eleven subjects we found four who seemed to be of this relatively versatile type—A., C., G. and Hs.—though the latter differs from the other three in the extreme importance which he attaches to the vocal-motor, and especially the lip-motor, factors.

(2) The other group consists of those subjects who have certain especially favored kinds of imagery which they use with considerable constancy in the various tests, and who practically omit, as far as actual use is concerned, certain other forms. They may be able to call these up by a special effort, but they almost never use them if there is a chance to deal with the situation in terms of their more favored imagery. (It should be noted in this connection that none of our subjects were even approximately lacking in some form of the "inner speech" complex. However strong a visualizer one might prove to be, he also used, on occasion, either the auditory-vocal-motor combination or the vocal-motor alone.)

In this group we may sub-classify our subjects as follows:

a. Those in whom the visual is well-developed and apparently very important. Articulatory (vocal-motor) is also present and is often the dominating form for tests involving the use of words. Auditory is reported as almost or entirely lacking. S. and Sun. represent this group.

b. Like the preceding group in absence of auditory imagery and marked dependence upon vocal-motor, but with an additional deficiency in visual, both verbal and concrete. One subject—H.

c. Those in whom the auditory-vocal-motor verbal is the predominant type for the great majority of situations. Visual verbal practically never appears. Concrete visual is rather more frequent, but there is a decided tendency not to use it if the situation can be handled in verbal terms. Three subjects—Ad., T. and V.—constitute this group. P. belongs partially with this class, in that his visual imagery, while fairly abundant, is very vague and lacking in detail. In the verbal complex the auditory is the dominant factor in his case.

## B. EVALUATION OF METHODS.

### 1. *As Subjective or Objective.*

We have indicated that our first dependence in every case was upon the subject's introspection. In our use, therefore, all the tests described were treated as either purely subjective or as a combination of subjective and objective. Yet such a use might justify us in a later adoption of any of these methods as purely objective. At least we are justified in raising the question as to our present evaluation of the tests from this point of view. We should group them now as follows, according to our opinion of the most profitable use which can be made of each test:

*Subjective.*—Reading tests (as described), solving arithmetical, geometrical, physical and other problems, rhyming tests[5], the majority of the memory tests, problems in motor control, such as drawing, many of the distraction tests, as well as an indefinite number of others which might be devised to meet the demands of particular situations.

*Subjective and Objective.*—Spelling backwards (oral) and pronouncing from words spelled backwards, description of pictures from memory, memory tests with words similar in appearance, but not in sound and vice versa, sorting and matching colors and certain of the distraction tests.

*Objective.*—We have no tests to offer as satisfactory for a purely objective use. The results are at best merely confirmatory of the introspections and should always be interpreted in the light of these. Even in the tests where the correlation between excellence of performance and the use of a given variety of imagery was most satisfactory, as in the reports on pictures, a purely objective application of the results would be hazardous because of the difficulty in deciding where to draw the dividing line between groups. An arbitrary location of this line would almost invariably result in errors of diagnosis. Moreover, it should be noted that the objective tests as a whole place an undue emphasis on the *accuracy* of imagery as a basis for the determination of type.

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[5] The rhyming tests may be considered objective in a very general way, in that the ability to perform them at all seems to indicate with certainty the use of some form of verbal imagery other than visual. It is not equally clear, however, that failure would indicate the reverse.

### 2. *With Reference to Their Value for the Analysis of Particular Kinds of Imagery.*

#### a. ANALYSIS OF VERBAL IMAGERY.

TO BRING OUT VISUAL FACTORS. *Spelling backwards and pronouncing from words spelled backwards; memorizing,* (1) *Roman and Arabic numerals,* (2) *Words alike in sound but not in appearance.* The records show that subjects tended to use visual verbal imagery for these tests if it was in the least degree a natural form for them.

TO BRING OUT THE AUDITORY-VOCAL-MOTOR COMPLEX. *Making lists of rhyming words, memorizing words similar in appearance but not in sound.* These tests tended to minimize visual factors and bring the auditory-vocal-motor elements to the front, though they did not serve to distinguish between the different members of this complex. *Combination of the above tests with vocal-motor distractions.* This device was planned to analyze this complex more thoroughly by eliminating or at least reducing the vocal-motor factors. The test did not, however, prove successful for this purpose, if the subjects' introspections can be trusted. It did seem to be of value as an intensification of the results gained by the use of the above tests without distractions: *i. e.,* it forced even the most visual of the subjects to use something other than visual verbal imagery.

#### b. ANALYSIS OF "CONCRETE" (NON-VERBAL) IMAGERY.

GENERAL CONCRETE IMAGERY. The only tests of the present series which had any such breadth of scope were those involving *reading of descriptive passages.* Qualities belonging to most of the sensory fields were suggested in these. In some cases these references proved quite effective in arousing the "illustrative" imagery, while in others nothing but verbal imagery was stimulated. The first essential for success with this test is the careful selection of passages. Many descriptions fail to arouse concrete imagery even in those subjects who can command it with readiness.[6]

Concrete Visual Imagery. *Certain of the above-mentioned reading passages, reports on pictures, sorting and matching tones and shades of colors, certain of the physics problems involving manipulation of concrete materials.* Absence of concrete visual imagery in these tests furnished rather satisfactory evidence of some degree of weakness in this form of imagery. On the other hand, absence of such a report for the memorizing of simple forms and colors seemed more ambiguous, since it appeared to be true that visual imagery was often omitted, not because of any deficiency, but because the verbal imagery was quite adequate for the performance of the task.

## C. THE FUNCTION OF IMAGERY.

Considering the importance which is at present attached to this problem and the experimental evidence which is being offered pro and con, we feel that a brief statement of the bearings of our experimental work on this question is called for. It will be remembered, however, that we made no systematic attempt to investigate this issue, so that whatever contributions we have to offer come merely as side-products of the direct line of our work. Such being the case we do not intend to enter into any detailed account of the various functions which imagery may serve, but rather simply to indicate our evidence as to whether imagery has any important functions in connection with common situations, or whether it is a mere accessory that may perfectly well be dispensed with.

We may frankly admit that our procedure was such as to force into prominence evidence of the functional value of imagery and to obscure indications that it is non-essential or unimportant. This is due primarily to the fact that we have been aiming throughout for tests which did call forth imagery, and, in a large part of the work, have been striving definitely for tests which should demand the use of certain particular forms of imagery. Accordingly we have not only made no attempt to discover problems which could be handled without any dependence upon imagery, but, more than that, where it has appeared that we had inadvertently introduced such tasks we have promptly changed our methods or dropped the tests. We are not, therefore, justified in making any general statements on the negative aspects of the question. We may, however, have some positive contributions to offer, and also some suggestions, based on the tests just mentioned, which proved unsatisfactory for the analysis of imagery, as to conditions under which tasks may be performed without the aid of imagery.

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[6] The more exact study of the various forms of concrete imagery was impossible within the limitations of the present investigation. The analysis was carried further simply along the one line of visual concrete imagery.

We shall consider the latter aspect of the question first. We have found three general conditions under which there tended to be a sparsity of imagery reported. (1) The first of these is easily dispensed with, as it is simply the case of great introspective difficulty. This was often noted and commented upon, especially in connection with the most difficult problems, those which involved most attention to the performance of the work itself. Even our best introspectionists sometimes reported that they had been so absorbed in the operation that they could not tell how they had done it, or that they found themselves unable to distinguish satisfactorily between the processes which were involved in the work itself and those which appeared in the subsequent attempts at introspection. This difficulty usually grew less as the tasks were repeated, but in any case it is not particularly significant with reference to this point. In so far as it persisted it simply left us without evidence on either side.

(2) The second condition which we have noted involves a genuine reduction in the imagery content. We refer to the tendency toward the establishment of automatisms in all the more habitual sorts of tasks. We have commented on this factor in connection with the reading, the spelling, the simpler arithmetical operations, etc., and it has been with the desire to break in upon this tendency that we have introduced the variations which make of the work a real problem. We have had abundant evidence to convince us that, as a process becomes well habitualized, it may

be performed without the aid of imagery and with a minimum of accompanying consciousness of any sort.

(3) In the third place we have found that where a reaction in perceptual terms is possible, imagery may fail altogether to appear. It was here that we met with difficulty when we attempted to use certain tests involving recognition or discrimination. This was particularly true for the few tests which we introduced, calling for recognition of tones, and was one of our reasons for dropping these particular experiments. It was less true in the matching and sorting of different color tones, but appeared quite frequently even here. This is not, of course, a unique discovery on our part, but is the view of discrimination which has become so nearly universally accepted of late, since its controversial precipitation by Miss Gamble and Miss Calkins (49).[7]

We may turn now to the more positive side of the question, to see whether we have any evidence that the presence of imagery is ever a matter of importance. That we have had imagery reported for each of the tasks by each of the subjects may be seen by reference to our experimental data. The certainty and invariability of this response increase with the novelty or difficulty of the problem. Moreover, we find constant references by the subjects to the fact that the imagery is essential for the performance of the task. Sometimes the reagent distinguishes between the various forms of imagery used, designating one as essential to the operation and the other as unimportant or accessory. Sometimes he accounts for a failure by the inadequacy of his imagery, or for a marked success by a peculiarly satisfactory image. In connection with the spelling backwards, for instance, it was frequently remarked that the work was done better when a good visual image was secured. In general, we may say that we did not find it difficult to devise situations which made the use of some imagery imperative, a fact which we have already discussed with reference to the shifts in imagery. It was only necessary to make the work sufficiently difficult and to deny to the reagent perceptual helps, and imagery of some sort, adequate or inadequate, came to the front.

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[7] With his usual keenness of observation, Galton had already called attention to this fact in the following passage: "The visualizing and the identifying powers are by no means necessarily combined. A distinguished writer . . . assures me that he is exceptionally quick at recognizing a face that he has seen before, but that he cannot call up a mental image of any face with clearness." *Op. cit.*, p. 97.

We would call attention to the fact, however, that the subjects frequently insisted that other factors were equally important with, or more important than, the character of the imagery used. Thus, in the memory experiments, the presence or absence of associations between images was again and again cited as the determining factor for the learning of a series. We did not find the subjects reporting, however, that these associations appeared in the absence of images, though they often helped out vague and schematic representations. But some such material to be associated was always reported.

# V. APPENDIX.

In this appendix we offer certain material of a detailed character, which is supplementary to the statements of the text and which may prove of interest to other investigators in the field of imagery. It is not essential to the comprehension of the text, but represents in the main typical data from which the conclusions there offered were drawn.

## A. SPECIMEN PASSAGES FOR READING TESTS.

For convenience of reference we quote parts of certain passages which are most frequently mentioned in our discussions. The numbers indicate the number of the given passage in the series.

### 7.

"St. Agnes' Eve—ah, bitter chill it was!
The owl, for all his feathers, was a-cold;
The hare limp'd trembling through the frozen grass,
And silent was the flock in woolly fold;
Numb were the Beadsman's fingers while he told
His rosary, and while his frosted breath,
Like pious incense from a censer old,
Seem'd taking flight for heaven without a death,
Past the sweet Virgin's picture, while his prayer he saith."
—Keats: "St. Agnes' Eve," 1st stanza.

### 8.

(1) "Imagine two steel knife-blades with their keen edges crossing each other at right angles, and moving to and fro."—James: "Psychology," II, p. 458.

(5) "Can one fancy the state of rage and picture no ebullition in the chest, no flushing of the face, no dilatation of the nostrils, no impulse to vigorous action, but in their stead limp muscles, calm breathing, and a placid face?"—James: "Psychology," II, 452.

### 9.

### *Quarrel Between George Osborne and His Father.*

"After giving a great heave, and with a purple choking face, he then began. 'How dare you, sir, mention that person's name before Miss Schwartz to-day in my drawing-room? I ask you, sir, how dare you do it?'

" 'Stop, sir,' says George; 'don't say dare, sir. Dare isn't a word to be used to a captain in the British army.'

" 'I shall say what I like to my son, sir. I can cut him off with a shilling if I like. I can make him a beggar if I like. I *will* say what I like,' the elder said.

" 'I'm a gentleman though I *am* your son, sir,' George answered haughtily. 'Any communications which you have to make to me, or any orders which you may please to give, I beg may be couched in that kind of language which I am accustomed to hear.' "—Thackeray: "Vanity Fair," chap. XXI.

### 11.

"And the Elephant's Child's nose kept on stretching; and the Elephant's Child spread all his little four legs and pulled, and pulled, and pulled, and his nose kept on stretching; and the Crocodile threshed his tail like an oar, and *he* pulled, and pulled, and at each pull the Elephant's Child's nose grew longer and longer—and it hurt him hijjus!

"Then the Elephant's Child felt his legs slipping, and he said through his nose, which was now nearly five feet long, 'This is too butch for be!' "—Kipling: "Just So Stories," "The Elephant's Child."

### 14.

"Let a candle flame, a gas flame, or an incandescent lamp be viewed by reflection in a piece of red glass. Two distinct images of the source of light will be seen, one image being white and the other red. When the light is viewed *through* the glass it will appear red. Hence we conclude that the red image obtained by reflection must be formed by light which traveled through the glass and was reflected from the *farther* side, while the white image was produced by light reflected from the *nearer* surface of the glass."—Millikan and Gale: "First Course in Physics," p. 398.

### 17.

### *Scene in Antiquary Shop.*

"He placed the box on the counter, pushed back a pair of small hooks, lifted the lid and removed from its nest a drinking vessel larger than a common cup, yet not of exorbitant size, and formed, to appearance, either of old fine gold, or of some material once richly gilt. He handled it with tenderness, with ceremony, making a place for it on a small satin mat. 'My Golden Bowl,' he observed—and it sounded, on his lips, as if it said everything. He left the important object—for as 'important' it did somehow present itself—to produce its certain effect. Simple but singularly elegant, it stood on a circular foot, a short pedestal with a slightly spreading base, and though not of signal depth, justified its title by the charm of its shape as well as by the tone of its surface. It might have been a large goblet diminished, to the enhancement of its happy curve, by half its original height."—Henry James: "The Golden Bowl."

### 23.

(1) "The smell of illuminating gas seems somehow a more massive, extensive sort of thing than the odor of lemon peel. But if one lessens the disparity in the *intensity* of the two odors, by getting just the merest whiff of the gas and inhaling freely and deeply of the lemon odor, the spatial difference between the two begins to evaporate."

(2) "The case of auditory space is similar to that of smell. We are told, for instance, that the tones of the lowest organ pipes are far larger, far more voluminous, than those of the high shrill pipes. A base drum sounds bigger than a penny whistle, a lion's roar than the squeaking of a mouse, etc."—Angell: "Psychology," 4th ed., p. 74.

### 24.

### *Richard in the Forest.*

"An oppressive slumber hung about the forest branches. In the dells and on the heights was the same dead heat. Here where the brook tinkled it was no cool-lipped sound, but metallic, and without the spirit of water. . . . The breathless silence was significant, yet the moon shone in a broad blue heaven. Tongue out of mouth trotted the little dog after him; couched panting when he stopped an instant; rose weariedly when he started afresh. Now and then a large white night-moth flitted through the dusk of the forest. . . . All at once the thunder spoke. . . . Then there were pauses; and the lightning seemed as the eye of heaven, and the thunder as the tongue of heaven, each alternately addressing him; filling him with awful rapture. . . . Lower down the lightened abysses of air rolled the wrathful crash: then white thrusts of light were darted from the sky, and great curving ferns, seen steadfast in pallor a second, were supernaturally agitated and vanished. Then a shrill song roused in the leaves and herbage. Prolonged and louder it sounded, as deeper and heavier the deluge pressed. A mighty force of water satisfied the desire of the earth. Even in this, drenched as he was by the first outpouring, Richard had a savage pleasure. Keeping in motion, he was scarcely conscious of the wet, and the grateful breath of the weeds was refreshing. Suddenly he stopped short, lifting a curious nostril. He fancied he smelt meadow-sweet. . . . He was sure he smelt it fresh in dews. . . . After two or three steps he stooped and stretched out his hand to feel for the flower, having, he knew not why, a strong wish to verify its growth there. Groping about, his hand encountered something warm that started at his touch, and he, with the instinct we have, seized it, and lifted it to look at it. The creature was very small, evidently quite young. Richard's eyes, now accustomed to the darkness, were able to discern it for what it was, a tiny leveret. . . . He put the little thing on one hand in his breast, and stepped out rapidly as before.

"The rain was now steady: from every tree a fountain poured. So cool and easy had his mind become that he was speculating on what kind of shelter the birds could find, and how the butterflies and moths saved their colored wings from washing. . . . He was next musing on a strange sensation he experienced. It ran up one arm with an indescribable thrill, but communicated nothing to his heart. It was purely physical, ceased for a time and recommenced, till he had it all through his blood, wonderfully thrilling. He grew aware that the little thing he carried in his breast was licking his hand there. The small rough tongue going over and over the palm of his hand produced the strange sensation he felt."—Meredith: "Richard Feverel," chap. XLII.

27.

(1) "So spake he in prayer, and Phœbus Apollo heard him, and came down from the peaks of Olympus, wroth at heart, bearing on his shoulders his bow and covered quiver. And the arrows clanged upon his shoulders in his wrath, as the god moved; and he descended like to-night. Then he sate him aloof from the ships, and let an arrow fly; and there was heard a dread clanging of the silver bow"—Lang, Leaf and Myers: Trans. of Iliad.

### 28.

### *The Odyssey.*

As one that for a weary space has lain
  Lulled by the song of Circe and her wine
  In gardens near the pale of Prosperpine,
Where the Aegean Isle forgets the Main,
And only the low lutes of love complain,
  And only shadows of wan lovers pine:
  As such an one were glad to know the brine
Salt on his lips, and the large air again,—
So gladly from the songs of modern speech
Men turn, and see the stars, and feel the free
  Shrill wind beyond the close of heavy flowers;
  And through the music of the languid hours,
They hear like ocean on a western beach
The surge and thunder of the Odyssey.
—Andrew Lang.

### 29.

Den I wish I was in Dixie!
    Hooray, Hooray!
In Dixie land I'll took my stan'
To lib an' die in Dixie.
    Away, away;
Away down south in Dixie.
    Away, away;
Away down south in Dixie.

## B. EXCERPTS FROM INTROSPECTIVE COMMENTS.

Since introspective material is peculiarly difficult to summarize, we have wished to present certain typical passages from each subject's introspection, as an indication of the foundation on which our more general statements were based. They are of value, also, as showing a degree of variety in the nature of imagery which is somewhat lost sight of in the summaries.

### 1. *Verbal Imagery During Reading.*

In the following fragments we have separated all comments on verbal imagery from their general context, so that taken alone they give a very one-sided impression of the reading experience. For the comments on illustrative imagery to supplement this, see p. 148 ff. Numbers refer to the number of the passage in the series.

A.

1. "Hear myself saying some of the words. I emphasize those I imagine important, and there is a tendency to repeat a sentence quickly before going on to the next one." 4. "In reading rapidly there is much less aud.-voc.-mot. material and much more emphasis on vis. stuff." 6. "Perfectly clear mental aud. enunciatory imagery—my own voice and throat." 26. "Detailed aud.-voc. imagery of the words. Hyphens led to slowing up and probably threw articulation into prominence." 32. "Found that unless I could stop hearing words pronounced couldn't make speed. A good deal was read with purely vis. consciousness, but every now and then aud. elements bobbed up." 29. "Music at once. Difficult not to whistle."

Ad.

1. "The lips were closed and practically still, except at sounds like p, b, t, etc., when they were pressed more closely together. There was the constant formation of the words in the throat. During the skipping period (from one significant word to another) they tended to run together and to be indistinct, but at the significant words they were articulated slowly, clearly and emphatically. There was in addition an aud. image of the words, in the skipping places going along so rapidly that single words could not be understood, but at the significant places heard clearly and distinctly—in no particular tone of voice, except that the pitch was low." 4. "Need for haste resulted in the slurring of words." 11. "Peculiar feeling in the nose and throat when I articulated the cold-in-the-head words." 13. "Articulated only few words on each line distinctly. Rest slurred, both in artic. and in sound." 29. "Heard tune very distinctly. Tendency to sing. Feeling in throat. Heard as sung in amphitheater at Chautauqua."

C.

1. "Pronounced important words in each sentence (aud.) leaving out conjunctions and sometimes adjectives and adverbs, which I seemed to get vis. with sufficient strength." 4. "Tended to pronounce more important words as read." 6. "Repeated the verse (aud.) saying every word instead of only the important

ones." 7. "Read it through, pronouncing every word. I think I always pronounce every word when I read poetry for enjoyment, for the rhythm forms a large part of the pleasure." 11. "Said words of the 'Elephant's Child' through nose just as he did." 26. "Pronounced every word as read it. Pronounced those hyphenated slowly and hard." 16. "Went just as fast as could go. Didn't cover whole of every line. Didn't notice any pronouncing." 29. "Sang as read it. Both aud. and mot. elements—own voice."

## G.

1. Introspection on this passage chiefly concerned with comment on such things as "consciousness of experimental situation," "slow and careful reading," etc. Says at end "With the second and following sentences I began going more rapidly, getting no vis. imagery of about half the words, but feeling that I did get clear images of the crucial words." 6. "As the swing of it came back there came the aud. imagery of the music." 7. "There was an aud. echo of the rhymes and some verbal imagery of the mot. kind." 9. "No recollection of definite imagery." 10. "There was an aud. murmur of words as I read the passage—also a motor feeling of the word 'resonance'." 11. "More auditory imagery than usually, particularly at the words which the 'Elephant's Child' said through his nose. Also some more imagery at the underscored words. Pitch changed here." 20. "Aud. imagery of the words 'cock's shrill clarion' and 'echoing horn'." 26. "Hyphens tend to delay the enunciation, but I purposely disregarded them in some cases because they interfere with the rhythm." 21. "In first reading (most rapid vis. scanning) got neither aud. nor mot. imagery. In second reading (most rapid for meaning) I had a distinct sense of pause when the meaning required it. This was motor and probably also aud., as when one's voice gives the falling inflection." 29. "Heard singing—not in own voice for most part."

## Hs.

1. "Lip-mot. and aud. predominate. Vis. subordinate to these but still present. Lip-mot. present to the extent that it always retards me to have any one watch me, as I try then to check the lip movements." 4. "I tried to hurry sufficiently so as to cut out the lip movement accompanying the reading." 6. "The first few words started the stanza singing and the reading was practically an impossibility. The lip and larynx movement shared the field with the aud. imagery and the vis. was almost wholly lacking." 26. "Lip-motor accentuated by splitting the word into

syllables." 28. "Onomatopoetic effect." 33. "This was way above my rate. Seemed to reduce almost entirely to vis., though possibly an occasional aud. element." 11. "Very striking appearance of the 'talking through the teeth' and 'through the nose' type of imagery and an actual setting up of the sensations of closing the teeth and closing the post-nasal passages." 29. "Tune comes up immediately. Chiefly lip-motor with some aud."

### H.

1. "Certain amount of inhibited lip-mot. No aud. imagery noticeable." 4. "More pronounced lip-mot. Lips actually used." 5. "A certain amount of muscular feeling in the tongue and roof of the mouth—assisted somewhat, I think, by aud. imagery." 7. "Am quite sure the imagery was lip-mot. and perhaps a little aud." 9. "Quite pronounced lip-mot. in the effort to make the conversation stand out." 11. "*Very* noticeable lip-mot. reactions, especially strong on such as 'hijjus,' 'hurtig,' and rather noticeable on underscored words." 16. "Mot. imagery was used very little. A general slurring of the whole process, and apparently this caused a lowering of the apprehension of the passage." 18. "Very largely lip-mot. feeling of the rhythm. Where it was lost in a line this was gone over again. Quite a clear aud. image on the word 'shrill delight.'" 26. "Very distinctly felt it read. Hyphens tend to make me hurry." (In reproduction H. placed hyphens between rather than inside the words.) 29. "Quite impossible to read. It sang itself and the reading lagged along behind. If I had any aud. imagery, would not be able to say what kind of a voice was singing—male or female, high or low."

### P.

1. "The immediate image process was the aud., going with the vis. presentation." 4. "Actual mechanics differed from the usual reading as I skipped around. Process a vis.-aud. affair, the latter subordinated." 9. "Read conversational lines with emphasis—slight but more so than descriptive passages. Verbal imagery was my own, however, not the characters." 6. "Caught rhythm from first line. Attention on rhythm and diction—given in aud. terms." 11. "The two expressions where the 'Elephant's Child' is speaking through his nose had almost the effect of a reinstatement of the state of a nose with a bad cold—imagery rather. Aud. imagery right along." 21. "Aud. if words seemed synchronous with eye-pauses. Tended to blur sounds, however." 26. Hyphens "made some difference in

sounds. Tended to separate syllables." 32. "Aud. accompaniment somewhat slurred but cannot read without this."

S.

1. "The whole is accompanied by very definite articulatory imagery, as usual when I am reading something for immediate use." 9. "Artic. rather prominent on certain points, as 'dare,' 'cut off without a shilling,' etc." 11. "Artic. Motor of jaws shut." 26. "Artic.—but not affected by hyphens." 28. "Artic. slowed up at 'surge and thunder of the Odyssey'." 29. "The words fell into cadence (rhythm) accompanied by noticeable opening and closing of the glottis to regulate pitch in which words are usually sung. No aud." As a rule no difference in amount of artic, noted for more rapid passages. Says for 21, however, "Artic. present but not so noticeable. Words clipped."

Sun.

1. "No imagery was present." 6. "Had feeling of the rhythm, of the liquid sounds, especially l's and lilt of verses." 9. "In reading the first part had no imagery. After the underlined word '*will*' tried to get aud. images and had a little." 10. "At some of the words had a consciousness of the words as if I were pronouncing them to myself, without making any sound, while the organs of speech remained immovable. (Still I have a feeling as if they were moving.)" 11. "Some feeling of pronouncing the words inaudibly, especially in the more emphatic and repeated passages." 18. "Inaudible pronouncing accompanied all the lines. Felt hampered at listening [!] to this silent accompaniment." 26. "Feeling of stumbling and effort in reading. Disliked chopped-effect produced by hyphens. The rhythm of 'pa-tient-ly' was especially irritating." 29. "Feeling as though were singing. No sound, but had sensations of movement as though were going through singing. Don't think I moved vocal organs. Seemed more like going through melody than forming words."

T.

1. "Aud. images of every important word. Can't detect vocal-motor sensations or images." 5. "In rapid reading aud. images still there but not so prominent. Not sure that the unimportant words were pronounced." 6. "Somewhat more conscious of expression. Feeling of rhythm." 11. "Pronounced words as usual. Feeling about nose and back of mouth." 18. "Thing

that I really get pleasure out of is music of the words. Think there are movements of the throat as well as aud. intonation. Better inflection than if I were reading it aloud. Onomatopoetic effect." 26. "Pronounced every word. Tendency to drawl out syllables." 29. "Didn't do any plain reading. Sang it in own voice. Decidedly vocal-motor."

### V.

1. "Get sound of every word. Seem to hear own voice but don't get it in own throat much." 9. "Voices were very distinct. Would recognize them again. Ran through whole conversation." 6. "Heard it, but with it there were some throat movements. Rhythm strong." 11. "Heard that in my own voice, but it changed as one and the other spoke. Thing through nose just as it would have been." 13. "Didn't have time to pronounce words but did hear them." 29. "Sung it. Own voice but heard piano, too."

### 2. *Illustrative Imagery During Reading.*

### A.

No. 8. (1) "Can see them and instantly get 'creeps' up my back." (5) "Nothing but aud. vocal accompaniment as I read." No. 7. (Second verse.) "About half way through the verse I began to get illustrative visual images of a stone church interior with tombs, etc. Think this was rather artificially stimulated by my introspective attitude." No. 11. "Very distinct visual picture." No. 14. "In making real to myself the conditions of the test, I *see* the situated flames, glass, etc., and have a rather definite motor imagery (?) connected with movements of my hand for manipulating the glass and movements of my head for looking through it." No. 17. "Very complete series of visual pictures. Visual images not particularly vivid—rather as though seeing in a dim room. *Color* of gold. Shape not clear until last line." No. 23. "Vis. of objects. Reinstatement of situation of smelling—but mainly in word forms (pungent, etc.) with perhaps a trifle of sniffing. *Can* get olfactory image of lemon." No. 24. "Vague flitting visual of scene. Quite definite of dog. No aud. Perhaps slight organic reaction—dryness of mouth, etc. Running fire of visual through latter part, but nothing else except a little organic until the last when got definite sense of contact with the palm."

### Ad.

No. 5. "Vis. images of two men." No. 8. (1) "Cold shiver up and down my spine; very vivid auditory image of a high, squeaky, grating noise; vis. image of two knives, but not in motion and no particular sort of knives, except that they were two fairly large sized bone handle pocket knives with the big blade open in each case. They seem to be unsupported, just floating or hanging motionless in the air. Tendency to make some movement to stop the racket and to get as far away as possible." (5) "Nothing more than words." No. 7. "Unusually strong effort to get vis. imagery which succeeded rather well, though the images did not come until after the vocal-motor auditory process had started. (That is the trouble with poetry—needs vis. images.)" No. 11. "Vis. imagery much stronger than usual. I could actually picture a cartoon of the struggle, and of the creaminess of the water." No. 14. "Lingered over each one until got rather definite vis. images located on table. All three lights and red glass lying on table. Motor tendencies to grasp. Got muscular (?) or vis. (?) image of turning around and holding glass up to look at it." No. 17. "Didn't understand expression 'pushed back hooks' until got vis. image accompanied by motor tendency to move hand. Vis. image of 'nobody in particular' setting things aside from *dark red* satin mat. Got yellow color of the bowl and shape, which changed with the description." No. 23. "Thought over series of odors. Suppose was some odor imagery. Seemed to get several very distinctly." No. 24. "Vis. image of birds, of moon and of dog. Aud. of brook. Faint, indefinite, unlocalized aud. image of thunder and vis. (trifle more vivid) of lightning. Aud. of patter of rain. Vis. of weeds during flash. Vis. of 'curious nostril.' Motor tendency to sniff. Vis. and aud. of rain from tree. Cold shivers later."

### C.

No. 5. "A vis. picture came up of the two sitting at the table and of George flapping his napkin and bowing the ladies out the door, and of the father drinking." No. 7. "Had fleeting vis. images of the man, the owl, etc." No. 8. (1) "It made me shiver and made my teeth grind together. A shrinking of the whole body and very unpleasant affective tone. Vis. image of the two knives but no aud., I think." (5) "Vis. image of an angry man (the father of yesterday's story) and beside him the calm face of a person looking like a nun and very pale." No. 11. "Strong vis. picture of everything that went on. All details of color and landscape strong." Had a bodily reaction for the pain in the "Elephant's Child's" nose. No. 14. "Picture of candle flame, red glass and two reflections. Localized with reference to self—out in the air. Some diagrammatic representation." No. 17. "Vis. picture of dark, old antiquary shop, old man, two people in front of counter. Man taking down box, opening it, etc. Bowl comes up very bright in dingy shop. Good deal of æsthetic pleasure out of image of bowl. Imaged at first as regular bowl with no foot—smooth. Changed with description. Box was kind of dark leather color—old and battered, lined with dark red satin." No. 23. "Can't make much out of statement about smells. Can't get memory image of them, but can almost get the smell of the lemon and the gas. Sniffed and tried to get something. Uncomfortable feeling for gas. Vis. picture of lemon." No. 24. "Picture of forest—in daytime and at night. Vis. and aud. of brook. Vis. of dog—kind of shaggy, black and tan. Realized that it was hot, but did not feel. More of a breathless kind of a situation. Vis. of big white moth. Strong vis. im. of lightning and of ferns. Saw rain from trees. Saw leveret and actually felt warmth. Some imagery for tactual qualities. Visualized stooping and reaching. No smell imagery and no sniffing. At end actually got tactual image of animal licking hand (like cat's tongue)."

## G.

No. 5. "Got a vis. picture of a waving napkin." No. 7. "Had vis. image of 'hare limping,' of Virgin's picture, and possibly of clouds of incense from a censer." No. 8. (1) "Visual picture of knife-blades cutting. Muscular reaction came quite naively. I closed my eyes tight and felt my mouth pulled down as if tasting a lemon." (5) "Color image of flushing. Feeling of limpness at word 'limp'." No. 14. "Images more sharply defined and clear than in other cases with sense of problem to be solved. Got a definite vis. picture of source of light at the left, a pane of red glass at the right, the two reflected flames—white one at left and red at right and a sense of the observer's position." No. 17. "Vis. image of yellow color and of shape of bowl as it is described." No. 23. "Vis. image of large space—for gas—and of slice of lemon. Vague notion of sharpness of lemon (olfactory (?)." No. 24. "Vis. imagery quite pronounced. Motor im. of little dog trotting. Definite vis. image of lightning. Got aud. of shriek and swirl of storm. Motor of drinking. Stopped short and lifted the nostril for smell. Tactual feeling, with muscular movement of small warm little animal with short hair. Vis.

of rain. Shiver. Vis. of colored wing. Sensation of thrill as finish description and come to animal's licking hand."

### Hs.

Nos. 5 and 7. Considerable vis. of scene, persons depicted, etc. No. 8. (1) "Vis. first, then after a moment more strongly auditory. Sets up a strong muscular sensation, almost a quiver and a very decided chill up my back. I do *not* like this one." (5) "A tendency to carry out the movements—dilation of the nostrils, clenching of teeth, etc., combined with vis. images of those acts." No. 11. "Perfectly clear vis. picture of the whole lengthening process." No. 14. "Referred to my own apparatus. Vis. image in terms of red and white." No. 17. "Very vivid vis. picture. Not much of people. Shape of bowl quite definitely. No image of lower part at first. Simply added on standard. Color definitely. Got actions quite clearly. Mat green." No. 23. "Made comparisons with effort at olfactory imagery. Used vis. images. No verbal that was conscious of. Either got smells or certain feelings connected with them. Do not seem able to get olfactory of lemon, though can get some of biting feel." No. 24. "General impression of kind of night. Didn't get aud. (though can get it). Vis. of dog—white. Both thunder and lightning. Aud. seemed stronger, but came after vis. Aud. of splash of rain very definite. Tactual of wet shoes. Can feel tongue licking—very vivid—but don't feel it up the arm."

### H.

No. 5. No illustrative for Nos. 5, 7 and 11. No. 8. (1) "Some vis. imagery and an aud. image which gives one an unpleasant sensation running down one's spine." (5) "Tendency to try each of the organic sensations mentioned—succeeded later by a slight vis. image of a calm face, then of a flushed one." No. 14. "A certain spatial imagery of the relative positions of the objects. No. vis. of colors." No. 23. "Certain amount of olfactory imagery." No. 17. "Certain amount of muscular feeling of opening the box, slipping back hooks, etc., together with a certain amount of visual imagery of the box and the satin mat (pale greenish (?). A distinct effort was made to get a vis. image of the bowl, but was unable to do so until the last phrase. Then got a vis. picture with more emphasis on the shape than upon any color." No. 24. "Vague vis. image of little dog—small and hairy. This would strike me as very vivid description, but I wouldn't get any of the suggested imagery. Don't know the little animal and, accordingly, don't get feeling. Periodic sentences do not arouse imagery."

P.

No. 5. "Building up meanings as a conceptual affair rather than definite image terms." No. 7. Small amount of rather vague vis. No. 8. "Definite vis. imagery. Two pocket-knives crossing, then moving. Organic reaction strong." (5) Some vis. imagery and some organic reaction, but not so much as in some of the others. No. 11. "Vague vis. image of animals and scene. Crocodile making water all creamy with his tail more definite. Also 'Elephant's Child' spreading his four legs and pulling." No. 14. "Rather concrete vis. imagery. Not definite room nor definite standards. Some im. of redness without boundaries. Did get the two images." No. 17. "Vis. imagery didn't come out very definitely. Aware that had it under definite control and could bring it out if I wanted. Rather a minimum of vis. for bowl. 'Old fine gold' called up more. No. vis. for shop or person. Perhaps a spatial orientation with reference to self. Kind of black, misty counter effect in front of self." No. 23. Process mainly verbal. Only slight tendency to image odors. No. 24. "Simply a succession of fleeting tendencies to visualize. Most definite thing (vis.) was moon in blue sky. Didn't visualize definite dog, though felt very confident of attitude toward dog. Got metallic sound. Thunder—both vis. of black sky and aud. of sound. Vis. of lightning and of great ferns. Aud. of shrill sound very distinct. Quite a little cutaneous for wet. At 'something warm' waited for them to develop—cutaneous image with unsatisfactory feeling that had nothing vis. to refer it to. At 'leveret' got hazy vis. image of mouse-like creature. Hazy vis. for rain, fountain, butterfly, moth. Splash of yellow color in front, but not localized spatially. Definite experience coming up arm. Got small rough tongue very well. Both cutaneous and organic reaction. Most definite appeal to cutaneous that remember ever getting from reading."

S.

No. 5. "Vis. image of a choleric, white-haired, rather short and heavy old gentleman sputtering, and a young man calmly leaning against a mantle across the room. Vis. image of a dinner scene."—Host of images for all objects and actions described. "Think I had two aud. images—the smack of the lips and the clinking glass." No. 7. "Vis. image of owl sitting on limb, very fluffy with feathers slightly ruffled on windy side.

Rabbit took a short mincing jump or two with left hind leg in the air. Vis. image of old gray-whiskered man, torch in left arm, red cold fingers sliding black beads on a string which had a black iron cross hanging," etc., etc. No. 8. (1) "Vis. of objects." (5) "Vis. of parts of anatomy in activity." No. 11. "Visual" (as well as artic. and motor). No. 14. "Vis. images of candle flame, incandescent light, piece of red glass about 10 x 6 in., reflection in glass—one red and one white." No. 17. Very profuse imagery. Described as though he were telling of something he had seen. No. 23. Doesn't have much meaning. Uncertain whether have olfactory imagery. No. 24. "Nothing but vis. imagery for first part. Vis. of lightning but none of thunder. Cutan. (?)—wet, cold, warmth. Vivid of wet clothes. feeling of rough tongue."

### Sun.

Nothing but words for Nos. 5 and 7. No. 8. (1) "Had image of something swinging—just movement, no object." (5) "Fleeting image of angry face." No. 11. "Fleeting image of river, trees and weeds along the bank." No. 14. Purely a logical process (in words). No concrete imagery. Gestured in describing to experimenter. No. 17. "Not definitely conscious of any vis. imagery. In thinking it over feel as if there must have been a dim image at words 'box,' 'nest,' but am not certain, also fleeting, fragmentary glimpses of the bowl and pedestal." *Can* get definite images of all the things when make the effort. No. 23. "Vis. image of gaslight in room. Feeling of sweetish (verbal or taste?), overpowering odor. Feeling of lemon odor as sharp and distinct. Vis. of lemon. Don't think I get any olfactory images." No. 24. "Vis. of haze, dog and moth, of forest, cloud, darkness, flash of lightning, ferns. Motor feeling of setting teeth at word 'savage.' Wave of warmth through hand at suggestion of warmth. Vis. of rain and of bird in rain. No tactual."

### T.

No. 5. "No visualization either of words or of scene." No. 7. "Illustrative imagery wouldn't come up unless I turned my attention to it. As soon as I did this I could call it up. Know that it is cold but have no feeling of it." No. 8. (1) "Visualized blades—first as scissors—vis. movement and it made me shiver." (5) "Tendency to visualize along with pronouncing." No. 11. "Came as near to visualizing as ever do. Not sure that it was unsuggested. Yet visualization only in a vague way. No coloring." No. 14. "Visualized more than in some of other things. Didn't see red glass. Located indefinitely. More a geometrical affair with motions of eyes and head. May be motions of eyes instead of vis. imagery." No. 17. "Some difficulty in getting meaning—especially description of bowl. Thought of it first as globe-shaped. Shape not clear at end. No vis. of color of bowl. Did not vis. general surroundings at all." No. 23. "Couldn't be sure without trying. Some vis.—not sure of smell. Tried to smell lemon—at least sniffed." No. 24. "A little tendency to visualize, but think this artificial. No colors. Tended to see little dog. Something of white and black for moth. No sound for brook. No heat." (This passage not finished.)

## V.

No. 5. "Seemed to be some vis. images: *e. g.*, table long. Didn't seem to see anything on it but a white cloth. People about the table, but don't see them definitely, except the father—rather large, fleshy, red-faced. Got movement (felt it) of serving dinner, etc., clinking of glasses (aud.), flapping of napkin (vis., aud., kinæs.). Impulse to get up. Aud. for smack. Olfactory of wine—sour, not sweet." No. 7. "Seemed to feel chill—actual temperature imagery, shrinking and tendency to shiver. Seemed to really get numbness. No vis. except of priest. Got him vaguely." No. 8. (1) "Took some time to get them, but finally did get, one in one hand and one in other—felt the coldness. Some vis. imagery, but also feeling, movement and noise. Some shivering at sound." (5) "Probably some emotional reaction." No. 11. "Seemed to see river and water. Could get coolness of it. Heard crocodile's tail swish through it. Saw a little of foam. Felt pull as spinal resistance. Could see Crocodile vaguely and 'Elephant's Child' not at all." No. 14. "Seemed to see a lab. table. Pane of glass (no color) set up. Saw a gas flame. When I got the two images, didn't see the reflections, but saw a diagram illustrating." No. 17. "Seemed to be behind the counter myself part of the time. Part of the time the man was there. Movements perfectly plain—as much mine as his. Couldn't get bowl very well. Had it silver and then glass, like a berry dish. Finally got more like a goblet—something of a burnished surface—perhaps in brightness and feeling of it." No. 23. "Got image of odor of gas, and, with more difficulty, that of lemon peel. Made judgment as a sort of sensory comparison. Got vis. of lemon." No. 24. "Didn't see them then, but seemed myself to be going along a forest path. Could sort of hear the twigs crackle. Smell of night, the heat and the stillness were there, but no clear vis. Did have vague image of little dog with tongue out. Could hear him pant. Heard brook. Got thunder. Got lightning as glare, not as streak. Got odor of meadow-sweet, smelt rain and forest odors. Tendency to put out hand. Sort of startled at the touch. Thought it was going to be a child and felt as if it were touching a child's face. Then changed and felt fur of little animal. Felt him put it inside his coat. Saw rain coming down. Felt little thing licking hand—first on back, then changed to palm. Before got this felt queer feeling—rather a chest constriction. Don't see animal at all."

### 3. *Pronouncing from Words Spelled Backwards.*

(I and II refer to the two rates of spelling—one letter or two per second. Where no difference in method was noted, the two reports are summarized together.)

A.

Combination of *vis.* and *enunciatory* imagery and *guess* work. Word often guessed from first few letters and last few.

I. *Vis.* images were followed syllable by syllable by *enunciation* wherever possible. *Word* sometimes came *vis.,* and sometimes by *enunciatory* jump.

II. Hardly any vis. images. Seemed purely guess work. Mainly *aud.* images backed up by *enunciation.* Striking change in type of imagery.

Ad.

I. Repeated letter to self as soon as heard, then next letter, etc., inverting order rapidly as went along, until they made a syllable. Pronounced this (*aud.-mot.*), continuing process until had word. (In prelim. tests in one case he formed the letters with his pencil, thus securing a vague vis. im.)

II. Tried to do as before but speed was too great. As a result he usually got one or two syllables this way, then had to guess.

C.

I. Variations in method, as indicated by following statements: "Tried first to get just *vis.* images of letters and found couldn't make much out of it. Then tried to get syllable as soon as given and *pronounce* it. Good deal of *vis.* still." . . . . "Think I am getting so that I *pronounce* last syllable, which helps."

. . . . . "I do mainly by getting *vis.* images of letters as they are pronounced. Then when last syllable has been spelled, I *pronounce* it myself. The rest is a heap of letters (*vis.*) in a kind of a mess, like a game of anagrams. I only run back over the order as given when in difficulty."

II. "Have to get *aud.-mot.* of letters backwards, then *aud.-mot.* of letters forwards, with what help the *vis.* gives, then *pronounce.* Sometimes just a mass of *vis.* letters." "Just a heap of letters. No time to pronounce last syllable when you go so fast."

### G.

*Vis., aud., mot.* in varying degrees, though main dependence seemed to be on *vis.* A change took place in the technique of the vis. image between the preliminary tests and the later. In the former the word was visualized backwards as the letters were given; in the latter the letters were placed so that when the word was completed it appeared in its normal arrangement. The change was made partly as a result of a suggestion and seemed to be an improvement.

I. Built the letters up visually in the right position as fast as they were given, pronouncing each syllable to herself as soon as she got it.

II. "Quite a different proposition." In some cases had to retain the *aud.* images and construct the vis. afterwards. In some cases had to retain the *aud.* images and construct the vis. afterwards. In some cases got the *vis.* as went along, but this took an effort. If she let herself go all she had was the aud. ring of the letters in her ear.

### Hs.

*Vis., lip-mot.* and *aud.* all present in varying proportions.

I. "This time the rate was slow enough to make it possible to build up the word as the letters were given, whereas with II this was often impossible, and the earlier part of the word was consequently lost. Think imagery was slightly clearer also." In another case speaks of putting letters in a sort of a frame.

II. More variation in method, as indicated by the following: "An entirely different process from the slower, in that I cannot do by syllables. It is simply an effort to remember the letters as given and then turn them around. I remember them mostly in *lip-mot.* and *aud.* terms, and turn them around with *lip-mot., aud.* and *vis.* imagery. Sometimes the whole word comes *visually.*"

As a variation from this method, for one set of five words he tried forming the word visually by putting the letters in a frame made by the red after-image from the space below the shade at the window.

His final conclusion is that he does better for this rate if he does not try to get the vis. as he goes along. He said at the end: "I find it essential to leave out the vis. image in the first part and get simply the *auditory-motor.* Then if I keep the letters so, I can use the *vis.*"

### H.

Depends entirely on actual *articulation* (semi-audible) of the letters as given. Found test very difficult and very trying. In earlier words and in some of later she kept the words in the order given, with no attempt to reverse them until the word was finished. It was this change which seemed most difficult. Often the letters as given were kept correctly, but the inversion could not be made without many trials or more properly guesses. For instance, she was heard to repeat the letters of the word—metaphor—correctly as r-o-h-p-a-t-e-m, but to invert these as t-o-m-p-h-o-r.

A more successful method was to transpose the letters rapidly as fast as they were given. This method required very close application and could not always be worked. Often a part of the letters would be inverted while the rest were kept in their original positions as given, making utterly senseless combinations.

For the most part it was a trial and error method of guessing words until she struck the right one. For example, for "lightning" she guessed "ligament," "align," "lining," "listening" before she got it. She speaks of the fact that in many cases she seems to have no consciousness of the middle letters—no memory of having heard them. (*Cf.* Sun.)

### P.

From the prelim. tests, speaks of trying to build up the letters on the power-house, but they kept jumping around. Pronouncing entered in, too.

I. "Can group the letters by twos and threes as go along (*vis.*) and pronounce (*aud.*). When I get through I have perhaps one-third of the letters of a word in syllables (*aud.*) which suggest a word." "It is characteristic of the slow rate that it is more dependent on *vis.* than is the fast." Visualized letters in script in order given, so that had to read off backwards.

II. "Good deal of that intuitive business. Rational methods didn't work. Was a jumble of *vis.* and *aud.* imagery in case of 'together,' but the word came as a jump. In the others I repeated the letters over about twice after the reader had finished." Last day—"Process predominantly *aud.* I used to try to make a syllable of the first two or three letters as you read them, but gave that up. I try now to keep them in an *aud.* way. When you get done I say them over about twice. Can usually approximate the first four and the last four, but get awfully weak in the middle, unless something especial comes out there. Then I tackle the ends and try to reverse the spelling. *Aud.* images most important. Some *vis.* but not always present.

### S.

*Vis.* images very important with more or less *articulation.* In some cases vis. images of the letters come immediately on hearing, in others *artic.* In either case, vis. images were built up into syllables, which were then articulated as such. Most approved method seems to have been to arrange the letters so that they appeared in their normal order in the syllables. In some cases, however, had to read the word off backwards. Speaks of the word as a whole coming by *artic.* with the *vis.* image as a mere accompaniment.

*More rapid rate was the easier!*

### Sun.

*Vis.* images apparently the main cue.

I. Word *visualized* as given and pronounced forwards. As a rule she does not succeed in visualizing the whole word at once. Usually gets first syllable and last, while the middle part remains a blank—a black space. Says it seems as though she did not even hear the middle letters.

I. Much more difficult to *visualize* the word. Largely guesswork from the first and last syllables. In one set (11-15), where she made her best record, she spoke of the fact that she was able to visualize better than usual.

### T.

"Tried to get last syllable, sometimes last two, just as given (*aud.*), then to catch the first syllable and put the two together. Just spelled in reversed order (aud.-mot.) and then pronounced. *No vis.* "Missed middle syllable almost every time, but pretty sure of first and last. Attention good. Worked with eyes closed. No tendency to keep vis. Sometimes pronounced *syllable* but not always." At end was able to keep all the letters of the word, reversing them as went long. Still no vis.

V.

I. "Simply reversed spelling (aud.-mot. terms) as fast as you went."

II. "Same way but couldn't keep up with you sometimes. Could hold series as *aud.* thing and go back over it. In some could almost reverse it as you went along."

(To the observer the most striking thing about V's procedure was the fact that she would hold the letters of the word so long and finally succeed in reversing them. Most of the other subjects had to get the word promptly or not at all. If they tried to work over the letters much they got these hopelessly confused. V., however, would frequently hold the letters for long periods trying partial reversals, but coming back to the letters as given.)

## C. DATA FOR PUZZLE PICTURE NO. I.

For each subject we have given, first, the details as reported, incorrect details being given in italics; then, any comments made by the subject when shown the picture for comparison with his recollection of it (obvious comments, with regard to simple omissions or to facts shown by the italics to be wrong, have not been repeated); and, finally, introspective comments on the method of recall.

A.

*Report:* Golden hair floating behind. Blouse effect like an Hungarian jacket—red (?)—skirt to ankles—blue(?). Upper part of sleeve yellowish, lower part *whitish.* Face about profile or *a little more.* Left arm crooked at elbow. Not certain about rt. arm, but think *it can be seen.* There may be a *little white apron.* Road leading to a little hut at back—flat roof and chimney with smoke coming from it. Road seems wide where she is, owing to perspective. Three (?) trees at right, sky with white cloud in it. One dwarf in upper part of left arm, facing as she was, toward the left. Other one in hair looking up.

*Comparison with actual picture:* Vis. image poor. Distance was magnified. Was not sure of large tree. Cloud quite wrong. Face good. House good.

*Method:* Entirely by vis. image.

Ad.

*Report:* First said, "I haven't any idea of it." Then reported girl with yellow sleeve and yellow waist, two dwarfs, one in arm and other *on chest.* She is *standing,* facing left. Has yellow hair trickling behind. Feet are visible, *brown* low shoes, *heels close together, toes out.* Dwarfs *facing observer—full face,* whiskers. Sky and sand visible—few lumps of ground, *may be some water.*

*Comparison:* Didn't get it very close. Don't recognize much of it now except the dwarfs.

*Method:* Guessed most of it. What I remembered was in purely vis. terms.

C.

*Report:* She was running. Her arms were doubled up. Her hair stuck out in a cone behind. It was yellow, with black lines in it. She had a red bodice and *green* skirt. Was some scenery behind her—green trees and a house. One dwarf in her hair, other on her sleeve. She had a *white* waist as well as the red bodice. Dwarf is turned upside down. One in hair had face turned upwards and the head came to about *the middle* of the cone of hair. She was running on a road or walk. The house was in upper left-hand corner of picture.

*Comparison:* The image of her was pretty good, except for mistakes in color. House thought of as higher in picture. Had tall tree in mind, but forgot to speak of it.

*Method:* Visual imagery altogether. Comparatively distinct.

Hs.

*Report:* She was running. Had yellow hair, flowing back in a sort of a pigtail. Had a *loose* sleeve with dwarf in it. Trees and distant scenery in picture. Her gown was blue. She faced left. Had *princess* gown, long skirt, sleeves unlike rest of dress. Had dwarf in her hair, with his head about at her head. Head of dwarf in her sleeve was about at her shoulder, and he was facing same way that she was.

*Comparison:* Her position was pretty correct. Image of blue indistinct, deeper. Tree, pathway and house entirely gone.

*Method:* Vis. imagery apparently exclusively.

H.

*Report:* At first could tell nothing about it. Then she said that there was one dwarf in her sleeve and that her sleeve was slightly *greenish.* This is all she would have told on her own initiative, but on further quizzing she added the following details, most of which are wrong: Think Snowdrop was *sitting down.* Her dress was *gauzy and green—all of one texture and color,* with probably a little white or lighter green. Not modern in style. Think she had yellow hair. At this point she was questioned again about the other dwarf, and this time she said she thought the other dwarf was in her hair. She doesn't know whether Snowdrop was in house or outdoors!

*Comparison:* Not at all like what I thought.

*Method:* In general, vaguely vis. Vis. of dwarf in arm. Only artic. was for dwarf in hair. No vis. for this.

### P.

*Report:* Snowdrop was running toward left—knees bent for running. *Semi-profile* or profile. She was well to front of picture. Picture tinted light. Horizon line low. Rolling land at back. Path going back toward left. Suggestion of a little hut. Arms *swinging.* Can't tell color of clothes or hair. Don't remember where dwarfs were. Think one was *in a long trailer hanging from her shoulder.* (This was a hold-over from another picture.)

*Comparison:* Background not as I thought of it. Colors lost.

*Method:* Remembered primarily as for simple, uncolored shapes and forms. A vague visualized picture came up gradually—was hard to get. No verbal.

### S.

*Report:* Her hair was yellow, streaming out straight and stiff. She had on a blue skirt and red bodice. She was running, with left arm bent and left foot back in edge of skirt. Back of her were some trees and a little hill. The dwarfs were in her head and arm. The one in hair was almost full face—his head up in her hair, her hair making his beard. Can't tell anything about one in her sleeve. There was some lighter waist above the bodice. Sleeve either yellow or white.

*Comparison:* Forgot little house. Didn't have trees at right accurately. The blue and red were pretty good, but bodice didn't come below waist line.

*Method:* All vis. imagery.

### T.

*Report:* Snowdrop was running. Had long hair, which streamed out behind and made the dwarf's beard. Other dwarf was on her sleeve. She was facing toward left of picture.

*Comparison:* Her general position correct, but size exaggerated. She was practically whole of picture. No colors remembered.

*Method:* Very vague vis. imagery. Remembering that dwarf was in her hair gave the idea of her running. In general, it was reasoning that kept it.

### V.

*Report:* There was a lot of color. One dwarf was in arm, one in hair. Hair yellow, streaming back. Think her sleeve was *blue.* She was *standing up.* Suppose she was outdoors. Head of dwarf in sleeve was near top. Don't know which way she was facing.

*Method:* Think I couldn't have told where they were if I hadn't said it at the time. I visualized the hair and seemed to visualize the sleeve, but it was blue.

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I

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# AUTOKINETIC SENSATIONS

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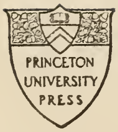
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I am under great obligation to my many subjects and especially to Professor Carr, Dr. M. R. Fernald and Dr. J. W. Hayes for their hearty and self-sacrificing coöperation.

H. F. A.

1.

# THE AUTOKINETIC SENSATIONS[1]

## Introduction

The visual illusion of motion known as the Autokinetic Sensations has had a curious and interesting history. First discovered by Humboldt in 1799, while he was observing the stars, it continued in astronomical literature for over half a century.[2] It was thought to be an actual movement of the heavenly bodies, which, like an eclipse, could be best seen in certain places and under certain conditions, and could be foretold with mathematical accuracy.

It was not until after the middle of the nineteenth century that the *Sternschwanken* was found to be an illusion.[3] Since that time, the illusion has appeared as a by-product of other experiments, principally those performed in the dark room, and has sometimes been reported by the investigators as a new phenomenon. Little thoroughgoing experimental work has been done on the illusion.

It is possible to experience the illusion either by fixating for a few seconds a star, or a faint light in the dark room, or a black spot on a white surface. Under these three conditions, the illusion shows certain similarities, movements being present, but there are differences in rate, amplitude and character of the movements.[1]

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[1] The illusion, which refers to the apparent movement of a faint, stationary light in the dark, owes its name to Aubert (6).

[2] Humboldt (1) first observed the phenomenon from a mountain peak in Teneriffe very early in the morning of June 22, 1799. The movement of the stars, often of considerable magnitude, was visible either with the naked eye or with a telescope. It lasted for seven or eight minutes, but stopped long before the rising of the sun. Thinking that the stars actually were moving, Humboldt gave the name *Sternschwanken* to his discovery.

[3] Schweizer (2) proved the movement to be illusory by having the same star watched simultaneously by different persons. Each saw it moving in a different direction. The author was unable to procure a copy of Schweizer's work, but found an abstract of it in an article by Exner (8).

In the experiments set forth in this paper, a faint light in the dark room was used throughout, for it made possible greater flexibility in controlling conditions. The subject was suggested by Dr. Harvey A. Carr of the University of Chicago, who had already done some preliminary work in studying the illusion. The following experiments are a continuation of his. Where his experiments were qualitative, these, as far as possible, have been made quantitative, and several points left untouched by him have been investigated.

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[1] The movements of the black speck on the white surface are all of small extent and there is a well defined tendency for the speck to return to the starting point. Schweizer (2), Hoppe (3), Aubert (6), Bourdon (9).

The *Sternschwanken,* according to Charpentier (4), is quite different from the illusion produced by fixating the faint light in the dark room. He alleges that in the former, the movement is small, changes direction rapidly, and slight concomitant eye movements can be noticed. In the latter, these conditions are reversed.

According to Aubert (6), distant objects, the contours of which are not sharply marked, may also appear to move.

## APPARATUS AND METHOD.

The light which was used as a fixation object was a two candle-power incandescent electric light enclosed in a light-tight box. The box had a changeable cover, in which was pierced a hole of desired size and shape. This hole was covered with one or more thicknesses of white paper to reduce the brightness of the light and to prevent direct fixation of the filament. The brightness was regulated by the number of pieces of paper pasted over the opening.

6 2/3 feet

The light was hung in the center of the wall which constituted the field of vision, at a distance of 200 cm. from the eye of the observer. The visual field was divided as follows:—the immediate point of reference was the zero point, or point of no illusory movement as determined by Carr (15) in his experiments on visual illusions due to eye closure. This point or area was found in his investigations to be with most persons slightly below the primary fixation position. Horizontally, vertically and on the two diagonals, points 10, 20, 30 and 40 degrees from the zero point were measured off, and nails driven above them so that when the box was hung from the nail, the spot of light would be directly on the appropriate degree mark. In this way, 33 positions in the visual field were marked off for examination, i.e., the central point and 32 peripheral positions.

The head of the subject was held firmly in a mouth-bit head-rest. This was done for two reasons:—first, to keep the head relatively stationary during any one fixation; and, secondly, to enable the subject to get back to the same position with reference to the field of vision time after time. The head-rest was so adjusted that the right eye of the subject, for which the zero point had been obtained, was 200 cm. from the light. Because the visual field was a flat surface, the points towards the periphery were increasingly distant from the eye of the observer.

A telegraph key, time marker, and kymograph drum were also used for registration purposes after the experiment had progressed slightly.

The method used was in many respects similar to that of all of those who have worked upon the illusion. The subject was seated comfortably in a chair, and, at a signal, took position in the mouth-bit head-rest. The illumination in the room was turned out and, after a sufficient interval had elapsed for him to get rid of the bright after-glow and after-images, the subject fixated the spot of light on the wall. Immediately upon fixation, the observer pressed the signal key. When the illusion started, the key was again pressed, thus giving the rate of start of the illusion. From the beginning of the illusion, the fixation lasted for 60 seconds. During the observation, the subject pressed the telegraph key once for each noteworthy thing which happened, such as turns in the direction of the apparent pathway of the light, stopping, starting again, etc. This time record was traced on the kymograph drum which was in a near-by room. At the end of the minute, the fixation was discontinued, the illumination in the room turned on, and the subject traced on paper from memory the approximate pathway of the illusion, putting a cross on the paper to correspond with each of the signals given by the telegraph key. In this way, it was possible to measure the duration of the illusion in any particular direction, the length of time it took it to start, the duration of any pause, etc.

Two of the subjects found it impossible to give an estimation of the linear or angular length of the illusory movement. It was necessary, therefore, in order to secure uniformity in treating the results, to substitute duration of movement for length of pathway in a given direction. This was often unfair, for the light might make a short, slow movement which would take a longer time than a long, fast one. But it seemed to be the only possible way of getting any quantitative results, so it was adopted.

The fixation light was hung first at the zero point, where it was fixated four times in succession, with a regular two minute interval between fixations. The ten degree points were then explored in the same manner and so on through the 30 and 40 degree positions. The next series was begun at the periphery and worked in towards the center.

This method was used for several reasons. In the first place, it was desired to make the work as definitely quantitative as possible. For this purpose, accurate measurements of some kind were necessary. In the second place, all of the previous work upon the illusion had been of a very general and incidental nature. According to the reports of the various previous experimenters, the instructions given to the subjects were rather vague. If the subject had any preconceived notion of what should happen, that very thing was likely to occur during the course of the illusion, if he observed it long enough, thus making it more or less possible for the subject to control the results. For that reason, a regular time interval was used throughout. In the third place, the duration of one minute was used because it was found empirically that that duration gave the best results with the least possible fatigue.

The greater part of the work fell upon four subjects, M. R. F., J. W. H., H. A. C., and H. F. A., although about 50 more were used incidentally. No conclusions are based upon the results of fewer than two subjects, and in most of the tests from three to six were used. Of the subjects indicated by initials above, all but M. R. F. wore glasses.

Each of the subjects but one, J. W. H., was found to have a zero point. With him, a point ten degrees below the primary position was used as the point of reference.

## METHODS OF SCORING RESULTS.

When the results were looked over, it was found that the ordinary pathway of the illusion was very far from being a straight line. It was often extremely crooked, having turned in as many as eight or nine different directions. The question then arose: What is the fairest and most accurate way of recording these results? It is quite obvious that the directional factors may be of some importance, but these factors often do not act regularly and continuously. For certain positions in the visual field it seemed to be entirely accidental when the light went in exactly the same direction twice in succession even with the same subject. In order not to make the results too unwieldy, the 360 degrees of a circle were divided into eight equal segments, each covering 45 degrees of arc. If the apparent pathway of the light fell twice in the same segment, it was said to be in the same direction. This arrangement allowed movements with a maximum variation of 22½ degrees to be recorded as in the same direction. By this means, each successive direction of the pathway was noted and averaged for each series of four tests, so that it was possible to find out in what directions the light tended most strongly to go. Not only was the frequency of movement in any direction recorded, but also the time that the. light spent in going in that direction. These two results were reduced to percentages and averaged in obtaining the final results which are given in this paper.

## EXPERIMENTAL RESULTS.

The first thing done was to determine the norm of behavior of the square light for the 33 positions on the visual field. Lights of different shapes were used to determine the effect of the shape of the fixated object on the direction of the illusion. A series of tests was then run through with lights of the same shape, but of different sizes. The illusion was then tested under conditions of monocular and binocular vision. Tests were also made to find out how great a part suggestion of a direction played in making the light go in that direction. The possibility of voluntary control of the direction and of the amount of the illusory movement were taken up and incidental tests made concerning the effect of the brightness of the light upon the characteristics of the illusion; the latter topic being one which others have investigated with some completeness.

### I. EXPERIMENTS WITH WHITE LIGHT 1 CM. SQUARE.

A. Universality of the illusion.—Of over fifty subjects experimented upon to test this point, not one was found who did not experience the illusion under some conditions. Sometimes several trials were necessary before the illusion took place. In the case of subject F., reported by Carr (14) as being unable to experience the illusion, it was found that when she was prevented from knowing whether the light was really stationary or moving, the illusion took place, although the light was of course actually motionless.[1]

B. Rate of start of the illusion.—On account of defects of the apparatus and even more on account of difficulties of judgment, the results obtained in getting the rate of start have a constant error of about one second.

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[1] Exner (8) reported that two of his observers could not get the illusion in a single trial. Charpentier (4) says that nearly all of his subjects experienced the illusion, but does not mention the percentage of those unable to do so, nor does he say anything about the conditions under which they were tested.

The average rate of start of this light for a total of 1960 trials with six subjects was 6.1 seconds. There is, however, a considerable variation in the rate of start of the illusion with the same subject, not only for different parts of the visual field, but also for the same part at different times. This variation seems to depend upon numerous factors. After-images often cause considerable delay in the starting of the illusion. Practice has the effect of making the light start its apparent movement more quickly. At the beginning of the series, the average rate of start for M. R. F. was 10.62 seconds. After having served as subject in the experiment for a year and a half, the time was reduced almost two-thirds. Certain other factors, such as the size of the light, will be taken up below.[1]

The variation for the different parts of the visual field for the same subject showed that the quickest rate of start occurred at that part of the field showing the greatest regularity in the direction of movements for successive trials. This ordinarily occurred towards the extreme periphery. The apparent exception to this rule was found in the case of H. F. A. With him, the fastest rate of start was at the center of the visual field. But even at that position, the illusion was quite regular in type, generally describing a clock-wise curve, the irregularity occurring at the points at which the illusion started and stopped.

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[1] In the literature, the rate of start of the illusion has been almost entirely neglected. Aubert (6), the only one who committed himself, places the time at 30 to 40 seconds. Fatigue has been mentioned as a factor which makes for the quick production of the illusion. Charpentier (4) says that the illusion takes place most easily after prolonged mental labor, such as a lecture, a long conversation, etc. Bourdon (9) maintains that retinal fatigue was found to be a favorable condition for the production of the illusion, as were also fatigue of the eye muscles, general fatigue and mental fatigue. Stimulation by alcohol and tobacco makes the illusion take place more readily. Carr (14) found that with marked fatigue of the eye muscles, the illusion started before the light could be directly fixated.

It is almost impossible from the literature to determine whether the investigators were referring to the rate of start of the illusion, or the rate of the apparent movement after it had started, or the ease with which it was produced. However, none of the previous investigators kept any exact time record of the rate of start of the illusion, their conclusions being based entirely upon impressions received in the course of their experiments.

There is also a well defined tendency for the rate of start to be quickest for those subjects who experience the illusion most markedly, as regards both rate and extent of movement. With the new subjects, the illusion was always slow in starting, while with H. A. C. who had observed the illusion more than any other subject, it took place immediately upon fixation in the great majority of the cases.

C. Direction of movement.—At the center of the field of vision, the pathway of the light for any one subject was very erratic. Nor did the light describe the same pathway for any two individuals in this portion of the field. The further towards the periphery the light was placed, that is, the more eye strain that was necessary to keep the light foveally fixated, the more likely was the direction of the apparent movement to be regular both for the same subject in different tests and for different subjects. The direction of this apparent movement tended to be in the direction in which the eye was turned. If the eye was turned to the right while fixating the light directly, the light showed a tendency to move to the right; and the more the eye was turned in that direction, the more likely was the light to move in that direction without variation. In the following table is given the peripheralwards tendency of the light. In the one case is given any peripheral tendency whatever, and in the other is given the tendency of the light to go in the exact direction of the eye strain. The results are given in percentages, averaged for six subjects and all positions on the visual field, a total of 1960 tests.

| | 10° | 20° | 30° | 40° |
|---|---|---|---|---|
| Peripheral tendency | 70 | 77 | 87 | 94 |
| In direction of strain | 26 | 34 | 56 | 91 |

This table brings out very strikingly the effects of eye strain on the direction of the illusion. The light seldom goes over the same pathway twice except at the extreme periphery, but merely shows an increasing tendency to go in a given direction time after time the farther from the center of the field the light is placed.

With each observer, there are one or more directions in which the light seems to "prefer" to move when at the more central portions of the visual field. With M. R. F. the tendency for the light to go in the right-left direction was much greater than for it to go either up or down. With J. W. H. and H. F. A. the light had a decided upward tendency. It is interesting to compare the upward tendency of the illusion with these two subjects and the similar tendency of a fading negative after-image.

There is a fairly large average variation between two series with the same subject and the same light. The average variation for the whole field, found by taking the difference in percentage of appearance in each segment for any two series, and getting the average of that, was found to be as follows for the two subjects whose results represent the maximum and minimum.

| | | |
|---|---|---|
| H.A.C. | Whole field | 5.00 |
| | Highest | 6.39 |
| | Lowest | 1.96 |
| M.R.F. | Whole field | 8.89 |
| | Highest | 18.75 |
| | Lowest | 0.00 |

In this connection, it may be interesting to ask whether the direction of the apparent movement of the light remains constant through long periods of time. Two persons who had served as subjects in Carr's experiments were also subjects in these. A comparison of the results of the two investigations showed a very great uniformity of the pathway in the peripheral portions of the field of vision. The same general tendencies and peculiarities held quite constantly for each subject even after the lapse of almost two years.[1]

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[1] Since, in most of the experiments reported, the light was approximately in the center of the field of vision, the direction of movement was not constant. With Humboldt (1), the movement of the start was either up or down or circling, with an invariable return to the original position. Schweizer (2), in referring to the movements of the stars, says that the movement is either circling or straight. In speaking of the apparent movement of a faint light in the dark room, Charpentier (4) states that while this movement is large and continuous in one direction, the direction may change after a time. He denies that the position of the eyes in the head has any effect upon the direction of the illusory movement. Exner (8) maintains that the direction of the movement depends upon the direction of the line of regard, but does not state in what way. Hillebrandt as quoted by Aubert (6), Bourdon (9) and Carr (14), say that if the light is in the periphery of the field of vision, the movement is in the direction of the eye strain. Exner (8), Gould (11) and Carr (14) call attention to the fact that there are individual peculiarities in the behavior of the light.

D. Rate of movement. The rate of movement is very irregular. The light seldom, if ever, starts out at full speed, nor does it stop suddenly, but accelerates and retards. Under the conditions of this experiment, the rate, as estimated by subjects H. A. C. and H. F. A., was seldom more than 10 degrees per second, and this speed was attained only at the extreme periphery. The light may move smoothly and continuously, or it may move in jerks.

Any disturbing factors, such as after-images, a second light in the field of vision, etc., made the movement much slower, if they did not check it entirely. When a screen was hung between the subject and the fixated light so that crossed strings appeared on the surface of the light, the illusion was very much slowed up. It gave the impression of a very small object trying to pull a heavy load along with it.[1]

E. Extent of movement. The extent of the illusory movement varied quite markedly for different subjects. For some it was very slight and so slow as to be hardly noticeable, especially at the central portions of the field of vision. In all cases, the angular displacement was greater towards the periphery. In this position, it often amounted to 40 or 50 degrees for some of the subjects. Ordinarily the light kept moving as long as it was fixated; in the central part of the field, however, the pathway was coiled up, while at the periphery it was straightened out, thus making the movement seem much more extended.

Two of the subjects were unable to tell with any accuracy the angular or linear extent of the illusion. Probably this lack of ability arose from three conditions: first, lack of knowledge on the part of the subject as to what a certain number of degrees represented; secondly, the lack of any fixed points of reference in the visual field; and third, because after the light had gone for some distance, it sometimes appeared, without any adequate movement, suddenly to be back very close to the starting point.

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[1] Charpentier (4) found the movement to be like that of a shooting star, but less rapid, having an apparent angular velocity of 2 or 3 degrees per second. Carr (14) found that under conditions of extreme ocular fatigue due to constrained eye position, the light often appeared to move 15 or 20 degrees per second, while under more normal conditions it was much slower.

This was due to some sort of revaluation of the ideational space construction of the subject.[1]

When, in the estimation of the subject, the light, in its wanderings, had approached one of the boundary walls of the room or the floor or ceiling, it often seemed to turn the right-angled corner and move either towards or away from the subject, though at other times it seemed to go straight through the walls. With J. W. H. the light, on one occasion, went straight down until it seemed to rest upon the floor. It "tried" to go down still farther and in its "efforts" apparently tipped the room, furniture and subject through an angle of almost 20 degrees. What actually happened was that the subject, in his endeavors to keep the light fixated, had tilted the table on to two legs and was holding it in that position solely with the mouth-bit head-rest while trying to keep his own balance.

This fact brings out in a striking way the illusion of eye movement which accompanies the apparent movement of the light. The subject is often vividly conscious of pursuit movements which he thinks he is making in following the light. This is more strikingly true for the more peripheral portions of the visual field. But when the illumination in the room is turned on, the subject finds that the eye has not wandered from the light which is in its original position. At times, even, there is a simultaneous illusion that the table or mouth-bit head-rest is going in the direction opposite to that of the light, though this is not always the case. One of the subjects actually twisted the head-rest loose from its support in his endeavor to follow the movement of the light.[2]

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[1] Charpentier (4) holds that the extent of the movement may be large, amounting even to 30 degrees in extent. Bourdon (9) agrees with Charpentier as to the extent of the movement, and states in addition that the light sometimes reaches a fixed limit, undergoing slight abrupt displacements from time to time about this final position. Carr (14) holds that under conditions of ocular fatigue, the extent of the illusory movement may be as much as 65 degrees, though this takes place only on the outlying portions of the visual field and with certain subjects only.

[2] Exner (8) calls attention to the fact that the fixation of the light is evidently much more constant than under ordinary conditions. Bourdon (9) found that there is a false consciousness of the direction of the line of regard. If the point had seemed to go up 20 degrees, the observer was

Even when the light was apparently nowhere near the boundary walls, illusory movements in the third dimension were not uncommon. These were often accompanied by a blurring of the outlines of the light.[1]

F. Suggestions due to the form of the light.—The shape of the light had some effect upon the qualities of the apparent movement. A round light, 1 cm. in diameter, often gave the impression of a balloon, floating freely through the air. Its turns were seldom angular, seldom abrupt, but generally through an arc of a circle. Often when turning in a curve, the light seemed to spin like a billiard ball in a masse shot. It was possible for this light to go as fast in one direction as in any other, there being nothing in the shape of the light which would tend to check movement in any direction.

The square light, 1 cm. square, often suggested a boat going through the water, especially if its course were such that it seemed to be going diagonally. This light, unlike the round one, seldom, if ever, turned through an arc, but usually through a sharp angle. Like the round light, it could go in all directions with equal facility.

The long, narrow light, 5.6 cm. by 0.18 cm., often reminded the subject of a board being raised or lowered or falling through the air. The movement was always fastest when the light was going in the direction of the long axis, and very slow when in the direction of its short axis. When this light appeared to go in any diagonal direction, it sometimes went like a sail boat with

clearly conscious of looking up, though he continued to look straight in front. After the light had appeared to go some distance to the right, he voluntarily shifted his line of regard back to what he thought had been the position from which the light had started. The light then seemed to be blurred, because it was seen in indirect vision. Consequently, he argued that the fixation was relatively exact throughout.

Bourdon also mentions a tactual illusion which sometimes accompanies the autokinetic sensations and is comparable to the one mentioned above. When the point was turning to the left, the subject felt that everything was turning to the left; the table on which his arms rested, the room, his own body. In his left arm, there was the feeling of turning to the left. When the point of light seemed to be going down, it appeared to the subject that the table on which his arms were resting was under pressure.

[1] Charpentier (4) denies movements in the third dimension.

a slight drift to leeward. Generally, however, in getting to a goal which was diagonally away from the starting point, the light tacked to do it, going in the direction of the long and then of the short axis. Several times, when this light was hung diagonally, the bottom part apparently swung about through an arc as though "endeavoring" to get vertically under the top of the light.

G. Additional description.—In general, it may be said that the apparent movement of the light is, or may be, of three distinct types, depending upon the length of the fixation and upon the position of the light in the field of vision.

In the central portion of the field, particularly when the light is first fixated, there ensues a slight quivering of the light. Sometimes this is confined to the edges, but more often the light as a whole seems to sway slightly. Following this, the light appears to move in some definite direction, sometimes in a straight line and sometimes along an arc. The direction of this apparent movement, in the central portion of the field of vision, is decidedly irregular. It may be in any one of the 360 degrees or all in succession. The rate is comparatively slow. In the peripheral portions of the field, the movement of the light, where the first phase is present at all, is very similar to the above description, except that there is more uniformity in the direction of the apparent movement. Sometimes, however, the first phase seems to be entirely lacking.

Phase one shades with more or less gradualness into phase two. This consists of a more rapid movement, generally straight peripheralwards, and the velocity apparently increases the farther the light seems to move. The velocity of the apparent movement also increases directly the further peripheralwards the fixated light is placed. After a variable interval the velocity of the apparent movement grows gradually less. The light finally turns and enters upon phase three.

The third phase consists merely of a return sweep, generally of about the same velocity as that of the outward sweep or slightly less. The light, in this case, often seems to approach and even go past the point from which it started. From here, it repeats substantially the first two phases of the apparent movement, though the actual direction may be quite different.

Between phases one and two, the light may appear to stop, or it may describe an arc very slowly. On the other hand, the two phases may shade into each other without any apparent line of demarcation. At times, also, phase one may continue for a time, then phase two may start, continue for a few seconds, then phase one may start again, followed once more by phase two. Phase three seldom occurred with the length of fixation used in these experiments.

## II.

Comparison of square light (1 cm. x 1 cm.) with the perpendicular light (5.6 cm. x 0.18 cm.) of the same area.

These tests were made only in the central portion of the field of vision, where the peripheral tendency would not overwhelm any possible effects of the shape of the light. In all 1300 tests were made with four subjects.

A. Rate of start.—The rate of start of the perpendicular light is, on the average, considerably greater than that of the square light of equal area, the latter requiring an interval of 6.1 seconds and the former 9.92 seconds (average for all subjects) in which to start the apparent movement. The slow rate of start of the perpendicular light as compared with the square one is interesting when it is correlated with the fact brought out by Dodge that a narrow, upright line is the best fixation object, the fixation movements being restricted to a very small area.

B. Direction of movement.—The effect of the shape of the light upon the direction of the apparent movement was entirely unexpected. The perpendicular light moved much more frequently than did the square one to the right and left, less frequently up and down and along the diagonals. The following table embodying the results of 800 observations will make this point clear.

| | U & D | | R & L | | DIAG. | |
|---|---|---|---|---|---|---|
| | A | F | A | F | A | F |
| Sq. lt. . . . . | 38.41 | 31.58 | 17.33 | 42.34 | 43.49 | 27.49 |
| Pr. lt. . . . . | 38.91 | 19.41 | 22.84 | 55.12 | 38.08 | 23.60 |

This was an entirely unexpected result, for it was thought that the suggestion due to the shape of the light would call forth up and down movements much more readily than the square light.[1] In the outer portions of the field of vision, the peripheral tendency due to eye position obscured the effects of the shape of the light, the pathway being similar to that of the square light.

C. Rate of movement.—In going to the right and left, the perpendicular light goes more slowly than does the square light, but in going up and down it goes more rapidly than does the square light.

D. Effect of fixating different parts of the perpendicular light.—No matter where the perpendicular light was fixated, it tended to move to the right and left more than it did up and down. When the top of the light was fixated, the right-left movements remained nearly constant, but the downward movements were lessened or inhibited entirely and the upward movements became correspondingly more frequent. Likewise, when the bottom part of the light was fixated, the upward movements suffered a similar checking or inhibition and the downward movements became much more frequent.[2]

E. Effect of using 2 square lights, 1 cm. square, one above the other.—In the first series of experiments, the contiguous edges of the lights were 1 cm. apart; in the second series, 3 cm. apart. Two subjects were used and a total of 194 tests was made at the zero point. When the upper light was fixated, the figure showed a tendency to go up more than in any other direction. When the lower one was fixated, there was a similar downward tendency. The two lights ordinarily moved in the same direction at the same time, but there were sometimes slight oscillations in one with no corresponding jumps of the other. In one case, while the upper light was stationary, the lower one rotated slightly about it.

There was no apparent difference in the rate of start correlated with the distance apart of the two series, although in both cases it was slower than that of the single square light 1 cm. on a side.[1]

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[1] Bourdon (9) used an upright line 22 cm. by 1 mm., with which he found it difficult to procure a simultaneous movement of the whole line, but after a long fixation it did move to the right.

[2] Bourdon (9) found that when he fixated the upper portion of the light referred to above there was an apparent upward movement of the light.

## III.

Horizontal and oblique light of the same size and shape as the perpendicular.

Although not a great deal of work was carried out with these lights, (about 379 tests), enough was done to find out that they followed the same law of peripheral movement as the other lights. Like the perpendicular light, each moved in the direction of its short axis much more than did the square light and less in the direction of its short axis than did the square light. With each, there was a tendency, not so marked as in the case of the perpendicular light, for the light to move in the direction of the end fixated.[2]

## IV. MAC ALLISTER'S FIGURES

A set of figures was prepared like those used by MacAllister in his study of "Fixation Movements". (17) These figures were, in general, of the arrow-head shape. The same light, turned four times through 90 degrees, ought to give quite different results if there is any influence in the shape of the light. The results do not bear out this assumption. The irregularity arose from the fact that the subject neglected one arm of the figure, paid attention to the other for a time, fixating one end and getting characteristic results for that kind of fixation, then shifted the attention to the other arm of the figure, causing often an almost right-angled turn in the pathway of the light.

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[1] When Aubert (6) used two lights, he found that they moved simultaneously and in the same direction. Exner (8) discovered that a second light checked the liveliness of the illusion and retarded the rate of start. The closer together the two lights were, the more the movement was inhibited. Bourdon (9) also found that the two lights moved simultaneously in the same direction, but noticed that they underwent slight, momentary, relative fluctuations.

[2] Bourdon (9) when fixing the right end of the long, narrow light referred to above, found that it moved to the right.

## V. EFFECT OF SIZE OF LIGHT ON ILLUSION

A. Rate of start.—With lights of the same brightness per unit of area and of the same shape, the size seems to have a direct influence on the rate of start. Averaging the 1520 tests of 4 subjects used in this experiment, the following results were obtained:

| Size of light | Rate of start |
|---|---|
| 1 cm. sq. | 6.1 sec. |
| 2 cm. sq. | 8.8 sec. |
| 3 cm. sq. | 7.6 sec. |
| 4 cm. sq. | 28.9 sec. |
| 5 cm. sq. | 29.1 sec. |

The bigger the light, the longer was the time necessary for the illusion to start in four out of five series of tests. Apparently, also, the brightness of the light has some effect, greater brightness acting like greater size, but no thorough-going experiments were carried out to test this point. Logically, if a light large enough and bright enough were used, the illusion ought to cease. It does, if the light is bright enough to illuminate intensely or even moderately the surrounding objects. With the largest light obtainable under the conditions of this experiment, a light about 10 degrees across and of brightness just insufficient to illuminate the surrounding objects, the illusion still persisted after a very prolonged fixation.[1]

B. Effect of size on the characteristics of the illusory movement.—In general, the larger the light is, the more it pauses and hesitates in the movement and the more difficult it is to get the movement started. With the largest lights, the movements were very ponderous and slow, with frequent long pauses. The smaller lights, 1, 2 and 3 cm. sq. moved almost continuously during the fixation. The light 4 cm. x 4 cm. was stationary 32% of the time that it was being fixated and the 5 cm. x 5 cm. light was motionless 25% of the time.[2]

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[1] Bourdon (9) found that a low brightness value of the fixated light favored the quick production of the illusion. With the point hardly visible, it was produced very quickly; but with a brighter point, a longer time was necessary. Exner (8) mentions the same point.

[2] Bourdon (9) used a light 25 cm. in diameter placed at a distance of 1 m. from the eye. With this light, the apparent movements of the light were very difficult to obtain, were of small amplitude, appearing and disappearing quickly.

## VI. THE ILLUSION IN MONOCULAR AND BINOCULAR VISION

In this series of experiments a round light 1 cm. in diameter was used. The three subjects who were used, completed a series of about 700 tests.

A. Rate of start.—Comparing the three kinds of lights, round, square and perpendicular, in binocular vision, the average rate of start of the round light is shortest, the respective rates being, in seconds, 5.12, 6.1, 9.92. The rate of start of the round light fixated binocularly is slightly shorter than with monocular fixation of either eye, but the difference is too slight to be of any considerable importance.

B. Direction of movement.—With both binocular and monocular vision, the light followed the law already mentioned of increasing the peripheral movement the farther the eye was swung in the socket. An interesting feature came out in connection with the monocular vision. With both the right and the left eye, the above law is followed on the average, but there are certain peculiarities which are deserving of mention.

With the right eye alone, the light showed a strong tendency to go either up or to the left, while there was little movement to the right or downwards.

With the left eye alone, this condition was exactly reversed. There was a decided increase in the movements downwards and to the right, while the movements to the left and upwards were considerably curtailed.

The binocular movement was not the resultant or average of the two monocular movements, but first one eye seemed to control the movement and then the other. The subjects were right-eyed for distant objects and left-eyed for near objects. This fact was brought out by having the subject observe the relative movements of near and distant objects produced by winking one eye and then the other, each eye fixating successively the near and far point. The 200 cm. between the light and the eye of the observer was normally just a little too far for the left eye. But the right eye, which ordinarily controlled the movement at the start, soon became fatigued and the left eye apparently stepped in to relieve it. This in turn became fatigued and the right eye, which had had time to become relatively rested, came to the rescue, and so on as long as the fixation continued.[1]

## VII. VOLUNTARY CONTROL

Voluntary control was possible for H. A. C. and H. F. A. It often took some time, but these two subjects were eventually able to make the light do what they wanted it to do. Various twists, winks, blinks, etc. were also effective to a certain extent. No new facts were brought out, but Carr's results were verified for these two subjects. M. R. F. was unable to secure voluntary control in the right-left direction, but could do so slightly in the up-down direction.[2]

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[1] Gould says (11) that "with the right eye, the head being erect or level, the light will sometimes slowly move, with varying rapidity, and without regular rhythm or beat, to the right and often upwards........With the left eye alone the movements are usually, but not always, to the left and sometimes upward. I suspect the character of the movements will depend upon whether one is right-eyed or left-eyed." Carr (14) found that the average direction of movement for monocular and binocular conditions of observation varied slightly. Right or left monocular vision tended, with subject C., to deflect the direction to the right and left respectively. The binocular vision seemed to be either a mean between the other two or else to be coincident with one of them.

[2] Aubert (6) was unable to control the illusion voluntary. Bourdon (9) states that a sudden and unexpected sound caused the light to move in the direction from which the sound came. The idea of a certain direction, or thinking of making a movement in a given direction, tended to make the light go in that direction. This result was not always accomplished immediately, a considerable time interval often elapsing, according to both Bourdon (9) and Charpentier (4). Bourdon (9) found also that desired direction might be produced by finger pressure upon the eye ball which was not used in fixating the light. If the pressure was on the upper part of the eye ball, it caused an upward movement; if on the lower part, a downward movement; if on the temporal portion, an outward movement; and if on the nasal portion, no movement at all. Carr (14) found that voluntary control could be exerted upon the direction, velocity and extent of the movements and it was more effective for central eye positions. Volition was found to be rarely, if ever, immediately effective. Strain sensations of certain ocular and facial muscles were found to be necessary for volitional control. Passive attention to a sound had no influence upon the illusion, but active attention had a slight, transitory effect, causing a deflection of the illusion in the direction of the sound. Visual attention had a similar effect. Contraction of the hand and arm caused a slight disturbance, the extent and

## VIII. SUGGESTION

There can be no doubt that suggestion plays a considerable part in determining the direction of the apparent movement of the light for certain positions. If the subjects obtained in any way a notion of how the light ought to go or was expected to go, it often went in that direction. The influence of the idea of the walls bounding the room, as was shown above, not infrequently affected the pathway of the light.

To test this problem more thoroughly, three näive subjects were obtained. These subjects, who were much interested in abnormal psychology, were told that the illusion was a new form of planchette which would form any simple figure or letter which they thought of while fixating the light. With one of the subjects, the suggestion worked perfectly, only one failure being made in 62 trials. The letters and figures were not always in their proper positions, sometimes being inverted, or suffering other displacements, but in all but one case, the desired letter or figure was formed. The subject was much surprised at this failure.

The other two subjects had difficulty in getting the illusion at first, but when they succeeded in obtaining it, the desired letter was formed in 80% of the cases.

## IX. EFFECT OF LIGHT BACKGROUND

The illusion took place, though not so rapidly, if there was a light background which was not so bright as the fixated light. Indeed, the objects in the room could be dimly discerned, as could also the nose, the rims of the glasses of the observer, etc. Under these conditions, the illusion still took place, but not so readily. After some experience with the illusion, even the stars on a fairly bright night can be seen to make apparent movements. But this condition obtains only when the attention is so firmly

direction of which was irregular. Deep and slow breathing gave only ambiguous results. A strong contraction of the jaws produced a noticeable downward deflection of the movement under all conditions. A unilateral strain of the eye in any direction resulted in a pronounced deflection in that direction. Twisting the body, in many cases, produced a deflection opposite to that of the body torsions.

riveted on the light that the other visible objects fade from consciousness. The more variegated and complex the visual field, the more difficult it is to elicit the illusion. Should a sufficient number of objects be in consciousness simultaneously, the illusion ceases.

## X. EXPLANATION

The attempted explanations of the illusion have been of three main types. It has been asserted that the illusion is central in character. This means that the exponent of the theory (Gould-11) has been unable to find any peripheral factors, such as tears, muscae volitantes, which, in his opinion, could explain the illusion. Nothing, then, is left but some kind of indefinite cerebral action, such as 'unconscious purposes to move' (Aubert-6). It is much like the ancient theory of the support of the world in space, pushing back the unexplained to something which equally requires explanation. Undoubtedly, central factors are present during the illusion, for if there were not, we could not be conscious of the illusion. But this central condition must be aroused by some significant and adequate means, i.e., in the periphery. It is only in this way that the central processes can make a false interpretation of sensory data, thus satisfying the definition of illusion.

The other explanatory theories at least take account of some peripheral factor. Exner (8) attributes it to the "circles of action of the retina". In explaining his "circles of action", Exner refers to the fact that a page of print, for example, will look merely like a gray rectangle at a certain stage of illumination. From this he argues that not only the part of the retina directly stimulated is excited, but the excitation overflows into the neighboring portions. The distance to which the stimulation from any one object radiates is called the "circle of action". If this overflow of stimulation is present in the case already mentioned, he argues, it is also present when a black spot on a white background is fixated. The awareness of this wandering about of the excitation within the "circle of action" produces the slight illusory movement of the spot.

This principle alone is insufficient, however, to explain the more extended illusory movements of a faint light in a dark room described by Charpentier and Aubert as sometimes amounting to 30 degrees. To account for these, Exner, after repudiating eye movements, which according to him diminish or prevent the illusion entirely, calls to witness the incompleteness of our orientation in the visual field and also the inexactness of our visual judgments of direction without control through retinal images. The more extended of the seeming movements are, then, illusions originating in the radiating tendencies of the stimuli. The unreal nature of the movements thus suggested we have no adequate means of detecting.

It is doubtful if the stimulation wanders about in the retina as Exner asserts that it does especially at the fovea; or, if it does wander, that the accumulation of the energy is first in one direction and then in an other as his theory seems to necessitate.

The remaining type of theory which might be called the eye movement theory, may be any one of three kinds. The first kind asserts that the illusion is due either to the unconscious fusion of the unconscious eye movements which are always present during fixation, or to the shifting retinal impression of the light brought about by the unconscious eye movements. To my mind this theory has been adequately refuted by Carr.[1]

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[1] While admitting that these unconscious fixation movements of the eye may play some unimportant part in the illusion, Carr (14) stated that "theoretical considerations may be urged against the theory as the *sole* explanatory principle. Why should the eye movements become integrated? What is the mechanism of this unconscious integration? Why does not the integration occur under normal conditions of perception? How and why should the process of integration be modified by the factor of position, etc.? Why should the process of integration achieve such diverse results under similar conditions? Factual objections may be given . . . . . Some people can obtain the phenomenon for some eye positions, but not for others. The illusion does not occur in normal perception. No one can deny the presence of involuntary eye movements under these conditions. If the eye movements produce the illusion in one case and not in the other, at least some secondary principal of explanation is necessary."

If a small, bright light is placed in the center of a dim larger one, Exner (8) maintains that while both move, the small spot wanders to and fro in the larger area. The movements of the latter are of the same character that they would have been if the central bright spot had been absent. The least eye movement checked the movement of both points. Exner conse-

The second eye movement theory asserts that the illusory movement of the light is due to driftings of the eye of some considerable extent—a sort of nystagmic condition. This approaches very closely to Carr's second type of illusion (14), and can not serve as an explanation of the first type for several reasons. In the first place, in obtaining the form of the illusion where the fixation does not leave the light, there is not sufficient wandering of the eyes, as was found by Carr, by actual observations of the eye experiencing the illusion. Experiments with after-images have shown that there is no appreciable drifting of the eyes from the fixated light.[1]

The third eye movement theory has been variously stated, but the key note of it seems to be that some sort of tension of the muscles is produced, either by fatigue of some muscle or group of muscles, or by some strain which has become increasingly greater in order to keep the eye in its position in the socket. This gives rise to a condition of excitement or lack of balance in the neuro-muscular system of the eyes. The illusion is somehow

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quently argues that eye movements cannot be the cause of the illusion. Carr's (14) experiments on the behavior of the light and a previously induced negative after-image, cited below, point to the same conclusion. Bourdon (9) and Simon (12), who repeated Exner's tests as to the relative movement of two objects, found that when the two objects moved, their positions relative to each other remained constant.

The main supporters of the first type of eye movement theory are Hoppe (3), Bourdon (9), and Simon (12). Dodge (13) gives an explanation which depends upon the same underlying principle, but differs in form of statement. This theory will be considered below.

[1] The following is a paraphrase of certain passages in Carr's article (14). To test the effect of involuntary eye movements, the relative movements of the light and a previously induced negative after-image were observed. In illusions of the first type, the negative after-image remained with the light and participated in the illusion. However, there were slight, irregular oscillations due to the involuntary shifts of the eye ball. Oscillations occurred in every test, though there were periods in which none could be detected. Generally no effective eye movements occurred during the marked and significant directional changes of the illusion. When such eye movements were present, their direction bore no constant relation to the illusory phenomenon. The results suggested that possibly steadiness of fixation might favor the velocity and uniformity of the movements. The relative oscillations of the light, and the after-image were due to irregular movements of the light.

caused by the conscious or unconscious interpretation of these conditions and factors.[1]

The objection to this theory is the alleged fact emphasized by Dodge (13) that the kinaesthetic sensations from the eye muscles can give us no information at all of eye movements. Conversely, strain on the eye muscles ought not to give us any reliable information concerning the position of anything in the visual field in relation to the head, even when it is directly fixated.

If Dodge's contention be correct, the only factor left to give any information concerning the movement of visual objects is some retinal condition, such as the succession and fading away of positive after-images. And Dodge would explain the illusion (13) as due to these after-images which are made possible by the shifting visual impressions brought about by the unconscious eye movements. But this is again referring it back to the unconscious eye movements and we have seen above that there are very cogent reasons for abandoning this type of explanation. It may be added that such after-images were never reported by the subjects.

Let us now turn to a theoretical consideration concerning the conditions under which an object may be seen to move. The instantaneous perception of movement must depend upon peripheral factors in the eye. These are limited to three classes of phenomena: the shifting of the retinal impression, the kinaesthetic cues from the various eye muscles, and the cutaneous sensations brought about by the pressure of the cornea and the lid and the temperature sensations (if such there be) aroused by exposing more or less of the cornea.

If all of these factors are examined, some light may be thrown upon the problem. The first explanatory assumption mentioned above emphasized the shifting of the retinal impressions, which would leave positive after-images, thus giving information as to the direction and amount of movement. In addition to the objections to this type of explanation of the illusion already cited, may be added the following: The unconscious eye movements come very frequently, averaging about 9 to the second and are of small amplitude, seldom, if ever, amounting to more than 2½ degrees. On this assumption, the illusory movement ought to begin as soon as the unconscious eye movements take place, an average time of 1/9 of a second. But this is not the case. There is, indeed, a slight quivering of the light immediately upon fixation which persists until the illusion has started. This might be explained very plausibly by the unconscious eye movements, but these slight shifting movements do not constitute the illusion.

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[1] The writers who advocate some form of this type of explanation are Charpentier (4) and Carr (14).

In the second place, if this theory were correct, the illusory movements ought to be quite variable, extending for a couple of degrees in one direction, then changing, but constantly circling about the point originally fixated. How could the slight eye movements account for illusory movements of the light amounting to 40 or 50 degrees in one direction?

Are the cutaneous sensations produced by the varying relations of cornea and lid sufficient to account for the illusion? Probably not, for if they were of any value, it ought to be in giving information as to whether the eye were stationary or moving. But how could this information help in experiencing the illusion? It is the very thing that the subject must be prevented from knowing in order to ensure the appearance of the illusion, for if he knows that the eye has moved, he may well judge that the light has not. In addition, if the cutaneous sensations of the lid are analogous to those of the rest of the body, they are soon fatigued and so could give the information to the subject for only a short time at best. The explanation of the illusion does not lie in this direction.

The only thing left is some sort of kinaesthetic data from the muscles. We have seen above that such data cannot be afforded by actual eye movements whether conscious or unconscious. The only condition left, then, is to be found in the strain sensations or nerve impulses coming from the eye muscles while the eyes are relatively motionless. A number of things which contribute to point to this conclusion will be taken up in due order.

But this is not the only factor which has to be taken into account in giving the explanation. The other one is this, that there is but one thing visible in the field of vision, or, if there are several, they interfere with the illusion.

The typical conditions of the illusion, then, are as follows: There is nothing visible in the field of vision except the fixated light. The only factors capable of informing the subject whether the light has moved or not are some shifts in our ideational space relations, brought about by muscle strain and tactual elements coming from the head-rest and table. The head-rest and table occasionally participate in the illusion, being more likely to do so, the stronger the autokinetic illusion is, and so may be neglected as a contributing cause of the illusion.

The illusion might conceivably be occasioned either by a shift in our ideational space construction while the light remains stationary, or by an apparent movement of the light in the stationary space. Either condition would satisfactorily explain the illusion.

When the eye is at any given position in the visual field, it is held there by the balanced action of the six extrinsic eye muscles. These muscles are not all of equal strength and some will become fatigued more quickly than the rest. When they are in this condition, it will take more of an effort, usually reflex in character, to hold the fixation constant; the fatigued muscle will be more strongly innervated. Consequently, more impulses, kinaesthetic and others, will be sent to the higher centers from that muscle. As these impulses have previously been associated with eye movements in a given direction, and since the fixation remains with the light, the subject will think that the light has moved in the direction in which the strain has been exerted. It produces the illusion of a pursuit movement. It is a matter of indifference whether the nerve impulses from the muscles arouse consciousness immediately or not, so long as they are capable of overflowing into other centers and thus produce the consciousness of movement.

The movement must also be attributed to the light and not to the ideational space, for if it were attributed to the ideational space, the movement would be in the direction opposite to that of the strain, whereas it actually is in the direction of the strain.

An illusion very similar to the autokinetic sensations is also experienced if the arm is extended in any direction and held in a stationary position by pressing a small piece of wood against the end of the finger strongly enough to prevent movement but not strongly enough to support the arm. Under these conditions, the arm seems to be moving upward, or in the direction in which strain must normally be put to keep the arm stationary.

If the arm is fatigued by holding it for a considerable interval in one position, e.g., straight out from the shoulder at the side, the illusion is much more striking. In the tests performed, the illusion was always in the direction of the muscular strain.

The illusory movement starts when the original muscular balance is sufficiently upset so that the extra innervation necessary to keep the fixation constant becomes strong enough to arouse the kinaesthetic and organic impulses and, through them, the associations mentioned above. The longer the increasing strain on that muscle or set of muscles continues, the longer will the movement continue in that direction. The shifts of direction of the illusion are due to the changes in muscular balance, on account of other muscles being subject to relatively greater strain, and consequently calling for greater innervation, with its accompanying results. Towards the center of the field of vision, there is naturally not so much strain on any one muscle as there is towards the periphery, and the balance is upset more frequently. Consequently, the direction of the illusory movement is more likely to be shifting and erratic towards the center of the field of vision. But as the eye is turned farther and farther, the strain on one muscle or set of muscles becomes greater and more constant and the resultant movement is therefore more regular and also faster.

Since voluntary control of the illusion is possible only by means of some such strains, it becomes easily explicable on this hypothesis. Attention in a given direction without looking in that direction means greater innervation (with its usual results in the muscles) in that direction without any resulting movements. Consequently the illusion takes place in that direction. In fact, Carr's statement (14) that steadiness of fixation seems to be a favorable condition for the illusion fits in remarkably well with the strain theory, for if the eyes were not steady there would be less preponderance of strain in any one direction.

The fact that with certain persons the illusion has a great tendency to go in a particular direction, as the right-left tendency of M. R. F. and the upward tendency of H. F. A., is also easily explained. The strength of the muscles was ascertained by using prisms. In the first case, the external and internal recti are weak, tiring easily and thus causing a right-left tendency of movement. In the second case, the external and internal recti are abnormally strong, were difficult to tire, so the movements in the right-left direction were few.

The perpendicular light showed a strong tendency to move to the right and left because there was not the same restriction to actual up and down movements that there was to those in the right-left direction. Consequently, the same amount of strain had not so much chance to arise. If, then, there is more strain in the right-left direction without corresponding eye movement, the light, according to the above assumption, ought to move oftener in the right-left direction, which it did. The reason for the slow movement of this light in the horizontal direction was because there was no very great superabundance of strain in one direction. It was enough, however, to produce the movement.

When the top of the perpendicular light was fixated, the only chance for free eye movement was downwards while the fixation was still on the figure. There is no reason why the right-left tendency of the light should change under these conditions, but there should be more strain on the muscles raising the eye without actually moving them. Consequently, the direction of the illusion ought to be upwards, which was the case. For exactly the same sort of reason, the light had a decided downward tendency when the bottom part of it was fixated.

Small areas move more readily and easily than the large ones because there is less chance for wandering of the eyes. The less wandering there is, the sooner the strain impulses should arise, and the sooner these arise, the quicker the illusion should start. Also, the more intense the strain sensations become, the longer and faster should the light move. This is exactly the condition met with when small lights are used.

Suggestion was effective because of a tendency to move the eyes in the suggested direction without actually doing so. Therefore strain would be put upon the muscles moving the eye in that direction, which would result in the illusion of movement in that direction.

Pathological cases and positive experiment tend to be strongly in favor of the strain theory of the illusion. As an illustration of countless numbers of cases of this character, may be cited the one taken by James (16) from Helmholtz. "When the external rectus muscle of the right eye, or its nerve, is paralysed, the eye can be no longer rotated to the right side. So long as the patient turns it only to the nasal side it makes regular movements, and he perceives correctly the position of objects in the visual field. So soon, however, as he tries to rotate it outwardly, i.e., towards the right, it ceases to obey his will, stands motionless in the middle of its course, and the objects appear flying to the right, although position of eye and retinal image are unaltered."

The conditions in the two cases are quite similar. In each, the fixation or position of the eye remains constant, the eye is not moved, but in each case, data which have meant movement in the past are present and are interpreted to mean movement. In both cases, the illusion of movement is a secondary affair, caused by another illusion, viz., that of pursuit movements. If during a pursuit movement, the object remains steadily fixated or in the same peripheral position, then the object must be moving, is the interpretation made, the rate being determined by the rate of the illusory pursuit movement.

The results of an experiment performed at the Psychological Laboratory at the University of Michigan[1] tend to bring out the same point under the normal conditions of the illusion. The subject was allowed to fixate the light until the illusion was well started, then the light was turned off and left off for a few seconds. The subject was directed to keep his eyes where the light had disappeared. The illumination in the room was then turned on and he was asked to tell where he was looking.

In no single case was he looking at the place where the light was, but in about 90% of the cases was looking at a point approximately opposite to that in which the illusion was going when the light was turned off. In the other cases, the fixation point was on the same side of the light as the pathway of the illusion, but between the place where the illusion had appeared to stop and what had been judged to be the starting place of the illusion.[1]

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[1] The author takes advantage of this opportunity to thank Professor John F. Shepard of the University of Michigan for the suggestion which led to the carrying out of this experiment.

This experiment proves that there is an unusual strain on a certain set of muscles while the illusion is being experienced. When there is no fixation point, the eye muscles tend to resume their balance, or to keep constant the amount of strain that was present with the disappearance of the illusion, thus pulling the eye in the direction opposite to that which the illusion had apparently taken. It was found that when the strain on the muscles was increased in the way that would be done under normal observation of the illusion, the eyes were very much nearer the place at which the light had disappeared when the illumination was turned on.

Another kind of experiment points to the same conclusion. If a great strain is put upon the eye to make it move in some definite direction while the eye-ball is held stationary, the illusion takes place in the direction of the strain.

Taking everything into account:—the results of the special experiments just mentioned, the neatness with which the strain theory explains the facts of the illusion, the entire inadequacy of any other explanation—it seems that some such hypothesis as that outlined above affords the only satisfactory way of explaining the illusion. It successfully avoids the difficulties raised by Dodge, and is supported by practical and theoretical data.

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[1] These variations in direction between the pathway of the illusion and the point fixated when the light was turned on were probably due to shifts in muscular tension. They probably would have produced changes in the direction of the illusion had the subject still been fixating the light.

# THE AUTOKINETIC SENSATIONS

## Historical Review

Despite the frequent references to the literature given in the previous pages, the lack of any connected historical sketch in English seems to justify a brief attempt at such a statement.

The term Autokinetic Sensations is used to describe the illusory movement of a small object or a collection of small objects which is seen after a longer or shorter fixation, against a relatively uniform background. Such apparent movement of the object is possible either in the light or in the dark. Historically, three main forms of the illusion have developed. In the day light, for example, a small black spot on a white background may be seen to move. This type of the illusion has been called by the Germans "Punktschwanken". In the dark, there are two forms of the illusion: first, the movements of the stars, called the "Sternschwanken", which was the form of the illusion first noticed; and, secondly, the movement of a faint light in the dark room, which has often been designated by the term "Scheinbewegung". Strictly, the term Autokinetic Sensations which was coined by Aubert was applied only to the last mentioned. but since all three are so similar and obviously depend upon the same causes, it seems justifiable to broaden the term to include all three types.

Chronologically, the first authentic information concerning the illusion comes from Humboldt (1). While upon a mountain peak 10700 feet above the level of the sea during the course of some investigations in Teneriffe, Humboldt saw the stars moving about in a most bewildering way. This phenomenon was visible either with a telescope or with the naked eye. After lasting for some 7 or 8 minutes, it ceased and soon the sun appeared above the horizon. Concluding that the stars actually moved Humboldt gave the name "Sternschwanken" to his discovery. Under this name it was frequently mentioned in the astronomical literature of the next half century.

The discovery that this phenomenon was an illusion was left to Schweizer (2). This fact appeared when Schweizer had the same star observed simultaneously by several different observers. It often happened that the different observers saw the same star going in different directions at the same time. If this was so, it could not be the result of any actual movement of the stars, so the obvious conclusion was accepted, namely, that the phenomenon was an illusion.

Turning now to the reports concerning the peculiar characteristics of the various types of the illusion, we shall begin with the "Punktschwanken".

Schweizer, Hoppe and Bourdon found that a black speck on a white background, as for example, a speck on a wall, would appear to move after a few seconds fixation. These movements were often irregular in direction and were much smaller than the apparent movement of the stars. Schweizer states that the spot, after its apparent movements, always returns to its original position. Hoppe and Bourdon do not mention this fact. The appearance reminded all of the observers of the movements of an insect, which was either crawling slowly, or which, stuck to the wall, was trying vainly to escape, now in this direction and now in that. Sanford states that the spot ordinarily moved either to the right or to the left for him.

Aubert calls attention to the fact that objects without sharply marked contours, such as distant flag staffs, masts, etc. appear to move after a period of steady fixation.

Turning now to consider the illusory movements of the stars, we find that this phenomenon has been mentioned by Humboldt, Schweizer, de Parville, Charpentier and Gould. According to Humboldt, the direction of the apparent movement was as follows:—The stars first went upward, then turned sideways and finally fell to their original position. Schweizer states that they either moved in ellipses or circles, going sometimes clockwise and at other times counter clockwise, or else they moved progressively. In either case they returned to their original position. De Parville says that the stars appeared to oscillate as if joggled and Charpentier holds that the movements were small, changed direction rapidly and that slight concomitant eye movements could be noted. Gould considered a star an unsatisfactory object from which to obtain the illusion, both on account of its dimness and because there are generally several of them close together. Yet with practice, he succeeded in obtaining the illusion with stars.

The extent of the illusory movements with the stars is relatively limited. Schweizer says that it may amount to several degrees and Charpentier states that it was small.

For Humboldt the illusion lasted for 7 or 8 minutes, then stopped.

Humboldt holds that the movement as visible through a telescope, though de Parville denies this. For de Parville the illusion stopped with very rapid blinking.

The apparent movements of an artificial star in the dark room have been studied much more thoroughly than either of the above illusions, and, consequently, may be treated much more in detail.

Carr found that this illusion might occur under three typical conditions:—

1. The point of fixation remained with the light and participated in the illusory movement. (2) The point of fixation apparently remained stationary and the light moved away from it. (3) A combination of the above two types occurred. The second type of illusion was less in extent, was less rapid, its direction was more uniform during any one test and was more constant from test to test for the same eye position than was the illusion of the first type under corresponding conditions. The illusion of the second type finally stopped. Accompanying this type of illusion were eye movements of about the same amplitude as the illusion but opposite in direction. A previously induced negative after-image remained motionless while the light appeared to move. On the other hand, in the first type, the after-image remained with the light and participated in the illusion.

### (A). *Universality of the Illusion.*

The greater part of the experimental work, however, has been done in connection with the illusion of the first type, so it will be profitable to take it up in considerable detail.

Charpentier found that nearly all of his subjects experienced the illusion, but does not give the percentage of those failing to do so. Exner found that there were two men in his laboratory who could not, at a single observation at least, detect any evidence of movement. Gould states that about one half of his observers did not get any decided movement of the light, but only a slight quivering or vibratory movement. Carr had one subject who could experience the illusion under no condition. Another subject obtained the illusion in the lower half of the visual field in only 50% of the cases. This subject was unable to obtain illusions of the second type.

### (B.) *Characteristics of the Illusion.*

(1) Rate of start. Nothing very definite has been worked out concerning the rate of start. Most of the investigators who mention this fact, say that it starts 'in a few seconds', or that 'it soon appears to move'.

(2) Direction of movement. Charpentier, who observed the illusion monocularly by looking through a tube at a light in a dark box found that the direction of movement was variable, but most often it traced a slight curve, moving outwards and upwards, though sometimes the direction was quite different. It sometimes described curves and zig-zags. Sometimes the direction was different in different tests. Bourdon found that the direction of the apparent movement was irregular. Sometimes it continued for a long time in the same direction. Hillebrandt, Sanford and Carr found that the direction of movement for successive tests for the same position depended upon the position of the eye in the head when fixating the light directly. In the central part of the field of vision, the direction of the apparent movement was quite variable. Here it was more likely to be curved than straight, while towards the periphery, especially

after the eye had turned through 40 degrees the light was quite likely to go in the same direction as that of the eye strain in practically a straight line for successive tests, this direction being peripheralwards.

(3) Velocity of movement. Charpentier found that the movement was like that of a shooting star, but less rapid, having an apparent angular velocity of at least two or three degrees per second. For Bourdon the movement was sometimes slow and sometimes rapid. Carr found that the velocity of the apparent movement depended upon certain conditions. It was often slow and irregular, especially at the central part of the visual field, but under conditions of fatigue from constrained eye positions, the light with some individuals often moved with an apparent velocity of fifteen to twenty degrees per second, giving the impression of a sky-rocket or of a rapidly moving shooting star.

(4) Amplitude of the movement. Charpentier found that the extent of the movement varied, though it might reach and even exceed thirty degrees. Exner gives about the same figures, stating that the apparent displacement often amounted to twenty or thirty degrees. Bourdon states that the movements had a large amplitude, the displacement being sometimes more than thirty degrees. Carr found that the extent of the movements was greater for extreme peripheral positions. Inside of the thirty degree zone, it was aimless in character. Under conditions of marked ocular fatigue and constrained eye position, the illusion for one subject was at least sixty-five degrees in extent.

(5) Duration of the movement. Exner found that the movement continued as long as he fixated, while Bourdon discovered that the point sometimes reached a fixed limit, undergoing slight, abrupt displacements from time to time about this final position.

(6) Movements in the third dimension. Charpentier says that no third dimensional components were *ever* noticed. The light always remained at the same distance from the observer. The other writers do not touch upon this point.

### (C.) *The illusion in indirect vision.*

Charpentier found that the illusion occurred in indirect vision. Bourdon states that it is not necessary to fixate the point, though the amount of apparent movement was smaller when the point was not directly fixated.

### (D.) *The illusion in monocular vision.*

Gould found that with the right eye alone, the head being erect or level, the light often moved to the right and often upwards. With the left eye alone the movement was usually but not always to the left and also sometimes upward. Carr found that right or left monocular vision with subject C tended to deflect the direction of the apparent movement to the right and left respectively. With binocular vision it seemed to be either a mean between the other two or else to be coincident with one of them.

### (E.) *The effect of incidental factors upon the Illusion.*

(1) The size of the light. Bourdon found, by fixating a luminous disc, 25 cm. in diameter placed 1 meter from the eyes, that the apparent movements were very difficult to obtain and when once obtained were of small amplitude, appearing and disappearing quickly.

(2) The brightness of the light. Exner holds that the less bright the light is, so long as it is foveally visible, the more lively is the illusion. Bourdon says that feeble brightness of the point favored the production of the illusion. With the point scarcely visible, it was produced very quickly. Yet a weak intensity is not indispensible. Brilliant spots, after a time, apparently move.

(3) The shape of the light. Bourdon found, when fixating a line 22 cm. by 1 mm., placed vertically at a distance of 1.5 m. from the eyes, that it was very difficult to get a simultaneous movement of the whole line. He finally obtained, however, a very marked movement of the line as a whole to the right or in the direction of its short axis. When he fixated the upper end of the line there was an upward movement. When the same line was turned horizontally, he finally succeeded in obtaining a slight but marked downward movement of the whole line. While fixating the extreme right end of the line, the whole figure seemed to go to the right.

(4) Voluntary eye movement. According to Charpentier, the fixation might be voluntarily changed around the object without stopping the illusion or changing its direction. According to

Exner, the least eye movement checked the movement of the point. Gould maintains that steadiness and continuousness of the gaze make the illusion more manifest and pronounced. To observe the effect of voluntary eye movement, Carr directed his subjects to rotate the eyes from one edge of the light to the other from time to time during the illusion and to note any coincident disturbances in the apparent movement. Two lights were used at different times; a square one, 1 cm. on a side, and a light in the shape of a cross which allowed movements of 10 or 12 cm. in length. The effects were found to be similar for both lights. Frequently no disturbance was noted, though generally a slight momentary influence in the same direction as that of the eye movements was present. The disturbance was momentary and never more than 2 or 3 cm. in extent. No permanent influence upon the direction or velocity of the light was ever noticed. Observations were made while attempting to fixate a distinct point on the light. These were compared with those obtained when the fixation was allowed to wander over the light at will. No differences in direction or velocity could be noted between the two conditions of observation. The fixation was also shifted suddenly for various distances and directions away from the light during the illusion. Such movements of more than two degrees tended to destroy the illusion temporarily, and the light appeared to be located nearer its original position. When the eye was held stationary in the second position, the illusory motion again appeared.

(5) Involuntary eye movements. To test the effect of involuntary eye movements, Carr observed the relative movements of the light and a previously induced negative after-image. In illusions of the first type, the negative after-image remained with the light and participated in the illusion. However, there were slight, irregular oscillations due to the involuntary shifts of the eye-ball. Oscillations occurred in every test, though there were periods in which none could be detected. Generally, no effective eye movements occurred during the marked and significant directional changes of the illusion. When such eye movements were present, their direction bore no constant relation to the illusory phenomenon. The results suggested that possibly steadiness of

fixation might favor the velocity and uniformity of the movements.

(6) Actual movement of the light. Aubert stumbled across the illusion while working on the perception of motion. He found that sometimes movement was seen when there was no objective movement, while at other times quite rapid objective movements were undetected. The direction of the illusory movement was in all but three cases the same as that of the actual movement of the fixation object. Carr moved the light objectively in a horizontal direction either two or five cm. at varying rates of speed. For those positions where the illusion normally moved in a vertical direction, a spiral or cork screw effect was obtained. When both moved in the same direction, the illusory movement was alternately accelerated and retarded. So far as could be observed, objective oscillations did not disturb the illusion in any way, for the total result was a composite of the oscillations and of the normal illusory movements for that position.

(7) Winking. Aubert found that by means of an intentional wink, he could often check this apparent movement, keeping the object in its correct position, but this did not always occur. Gould maintains that the inhibition of winking makes the illusion more pronounced. Carr found that inhibition of winking exerted no influence upon any characteristic of the illusion. Voluntary winks were sometimes effective and sometimes not, their effect being more frequent for central eye positions. With voluntary winking, an increase of the effect was obtained as long as the innervation could be increased.

(8) Finger pressure upon the eye ball. Charpentier found that finger pressure upon the eye not used in perceiving the illusion exerted certain influences upon the direction of the illusory movement. If the pressure was on the upper part of the eye ball, it caused an upward movement; if on the lower part, a downward movement; if on the temporal side, an outward movement; and if on the nasal side, no movement at all. In the above cases, the resulting direction was independent of the position of the eyes in the head.

(9) Head-rest. According to Exner, it makes no difference whether a head-rest is employed or not. According to Gould,

immobility of the head is a favorable condition for a pronounced illusion.

(10) Direction of the line of regard. Charpentier holds that various turnings of the eyes did not retard, prevent or influence the illusion in any noticeable way. Hillebrandt found that when the light was placed in the extreme periphery of vision so as to be fixated with great difficulty, the illusion took place towards the periphery and was the more striking the longer the fixation was continued. Exner contends that the direction of the illusion depends upon the direction of the line of regard. Bourdon found that, if in fixating the point, the observer shifted the line of regard without turning the head in relation to the body,—above, below, to the right and to the left—the movement of the point tended likewise to be respectively up, down, to the right or to the left. Carr's experiments confirm the belief that the position of the eyes in the head is a determining factor in the illusion. He found that its most marked effect was upon the direction of the illusion. Averaging all the cases, it was found that with subject C there was a marked tendency for the light to move towards the periphery of the field in 88% of the cases. This peripheral tendency increased with the distance of the light from the center of the field. The average percentage for all positions within 30 degrees of the center was 75. Outside of the 30 degree zone, the average was 95%, and for extreme fixation positions the percentage was 100.

(11) Previous eye position. To test this point, Carr directed his subjects to turn the eye towards the light from various directions at the beginning of the illusion. Care was taken to choose such distances that no after-effect of the previous fixation was present. A slight temporary disturbance of the same direction as that of the eye movement was generally observed. But no permanent effect was exerted. When the previous fixation was of longer duration, any eye position was found to exert not only a characteristic effect upon the illusion while the eye was in that position, but also to leave an after-effect which modified the direction and velocity of the illusion in a characteristic way for subsequent eye positions. The duration of the after-effect varied from nothing at all to one minute. It was a function mainly of

the distance and direction of that position from the center of the field and the length of time the eye maintained that position.

As a result of this experiment, Carr divided the field of regard into two zones, an inner and an outer. In the inner zone, the movement tended to be towards the periphery and in the outer zone it tended to go towards the center. This latter direction of movement was always quite rapid and was followed by a return sweep. The inner zone was elliptical, the shorter axis being vertical. The length of the two axes was approximately 45° and 50°. The influence of the outer zone was more pronounced and characteristic than that of the inner. The direction was practically constant for successive trials at the same position. There was found to be a minimum duration of fixation necessary to secure any result, this period decreasing with the eccentricity of the fixation position. There was a certain period of fixation necessary to secure the maximum result for any position. After the maximum of effect had been obtained, further fixation decreased the effect. Subject A had three zones, the outer and inner corresponding to subject C's outer, and a middle, corresponding to C's inner.

(12) Fatigue. According to Charpentier, the illusion takes place readily after prolonged mental labor, such as a lecture, a long conversation, etc. Bourdon agrees with this, and would add general muscular fatigue. He considers also that retinal fatigue and fatigue of the eye muscles cause the illusion to take place more easily. Stimulation by alcohol and tobacco is in addition a favorable condition.

(13) Attention. Charpentier found that passive attention, such as that given to a sudden and unexpected sound, caused the light to move in the direction from which the sound came. Carr found that passive attention to a sound had no influence upon the illusion, but active attention had a slight, transitory effect causing a deflection of the illusion in the direction of the sound. Visual attention had a similar effect.

(F) Voluntary control. Charpentier states that the light may be made to move in a desired direction by thinking of a given direction, perceiving another object in that direction, or by thinking of performing a movement in that direction. This was not always true, but it occurred in the majority of the cases, the percentage of successful cases and the length of time necessary to keep the attention focused upon that idea not being given. All of the observers at times succeeded in this voluntary control. Aubert, on the contrary, was unable to secure voluntary control of the direction of the apparent movements of the light. Bourdon, however, agrees with Charpentier in the ability to control the direction of the movement voluntarily, by thinking of a given direction or even by looking in that direction a little from time to time. At times it was necessary to attend for a considerable length of time before the new direction was obtained. At times, also, he obtained a resultant of the old direction and of the one of which he was thinking. The possibility of voluntary control was confirmed by Carr's tests. This control could be exerted upon the direction, velocity and extent of the movements and was more effective for the central eye positions. Volition was found to be rarely if ever immediately effective. Strain sensations of certain ocular and facial muscles were found to be necessary for volitional control.

(G) The effect of the tension of various muscles. Carr found that long continued and intense contraction of the hand and arm caused a slight disturbance in the majority of tests, the extent and direction of which was irregular. Deep and slow breathing gave only ambiguous results. A strong contraction of the jaws produced a noticeable downward deflection of the movement under all conditions. A unilateral strain of the eye in any direction resulted in a pronounced deflection in that direction. Twisting the body in many cases produced a deflection opposite to that of the body torsion. After fatigue had been induced, it was found that a rotation of the head around the anterior-posterior axis caused a change in the direction of the illusory movement.

## II. Other Illusions Involved.

One of Bourdon's subjects experienced an interesting tactual illusion which accompanied the apparent movement of the light. While the point was going to the left, for example, this subject felt that everything was turning with the point, the table on which his arms rested, the room and his own body. His left arm felt as though it were turning to the left. When the point of light seemed to be going down, it seemed to the subject that the table upon which his arms rested was under pressure, like a ship which is forcing its way down into the water. Another illusion noticed by Bourdon in studying the apparent movement of the light was the false consciousness of the direction of the line of regard. If the point had seemed to go up 20 degrees, the observer was clearly conscious of looking up, though his eyes were straight to the front. After the light had appeared to go some distance to the right, he voluntarily shifted his line of regard back to what he thought had been the position from which the light had started. The light then seemed to be blurred because it was seen in indirect vision and the eyes and head were turned to the left. Consequently, he argued that the fixation was relatively constant throughout.

## III. The Presence or Absence of Eye Movements.

The principal experiments to test this point were performed by Carr, though certain others will be taken up under the consideration of the movement of two or more lights. Carr used two methods, the after-image method and that of observing the eye which was experiencing the illusion directly through a horizontal telescope. By the first method, as has been mentioned above, there was disproof of any eye movements sufficient in magnitude to account for the extended illusions of the first type which he obtained. The observation of the eye through the telescope gave identical results. There were always present the slight involuntary twitchings of the eyes, but no extended movements or even drifts in illusions of the first type, but in this second type there were large movements opposite to the direction of the illusion.

## IV. The Illusion with Two or More Fixation Objects.

Charpentier maintains that with a group of small points close together, the illusion still persists. Aubert adds the information that both objects move simultaneously and in the same direction. Exner says that the presence of a second light retards the illusion, this effect being greater the closer together the two lights are. Nor did he find that the two objects moved simultaneously in the same direction. To test this point he used a black spot 1 cm. in diameter with a needle hole in the middle. This was so adjusted that the black spot and the bright hole could be seen easily. The result of fixation was that both seemed to move, but often the spot of light wandered rapidly to and fro inside of the black circle, often changing direction, but never reaching the edge of the black speck. The latter made movements of the same character that it would have made if the central bright spot had been absent. So the two movements were often independent of each other and could not be due to eye movements. Simon repeated Exner's tests as to the relative movement of two objects. Exner's results were not confirmed. When the objects moved they always moved in unison. Bourdon, in testing the same point, used a pale luminous disc 25 cm. in diameter which had an opening 2 mm. in diameter in the center. The movements of the point were easily observed, though it was difficult to follow the motion of the disc. The disc nevertheless followed the point, for when at certain moments, Bourdon paid attention to the apparent position of the disc, he observed that it corresponded to that of the point. Bourdon also used two lights side by side. It made no difference whether they were 4 or 22 mm. apart, whether they were placed horizontally or vertically with relation to each other. The two lights appeared to move simultaneously and to oscillate together. The movement was however, of but small amplitude. With a more complex figure, he further verified the simultaneous movement of the different parts of the figure.

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STUDIES FROM THE PSYCHOLOGICAL LABORATORY
OF THE UNIVERSITY OF CHICAGO

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# A Study of Cutaneous After-Sensations

By

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## I. HISTORICAL STATEMENT.

The phenomenon of cutaneous after-sensations has received its most elaborate treatment at the hands of Albert Goldscheider and J. Gad; Urbantschitsch, Dessoir, and Thunberg have given the matter some careful consideration, and perhaps a score of other writers have touched upon this problem in connection with their work in neighboring fields.

The cutaneous after-sensations, as will be further described, fall naturally into two classes—the primary and secondary,—but this distinction is not specifically recognized until 1892. The early authors speak sometimes of "Nachdauer der Empfindung", which would seem to indicate the primary after-sensation, but quite as frequently we find the term "Nachempfindung" without sufficient context to determine whether the primary or secondary phenomenon is intended.

This survey will be made as far as is practicable in chronological order.

In connection with an experiment on skin localization made by Kottenkamp and Ullrich[19] as early as 1870 it is stated that the subject did not attempt to localize the spot until "nachdem die Nadel entfernt war und die durch sie verursachte Nachempfindung aufgehört hatte". This casual recognition of the phenomenon would seem to indicate that it was at this time a well known fact, but I have been unable to find any extended discussion of the subject in the writings of Czermak, Weber, Fechner, and other of the older authorities.

In 1880, Funke[11] speaks of the long duration of pain sensations and the persistence of pressure after a "skin compression".

In 1881, Preyer,[28] seeking to compare the phenomena of color and of temperature, writes as follows with regard to the positive and negative after-images of these: "Nach Beendigung der Erwärmung oder Abkühlung bleibt zunächst eine positive oder gleichsinnige Nachempfindung zurück". This persists for a long time: "Wenn man aber weiter beobachtet, dann bemerkt man leicht, dass regelmässig die kalte Haut wieder warm, die warm kalt wird, indem die positive Nachwirkung schwindet". These cutaneous after-sensations are, he says, more enduring than those of the eye on account of the greater inertia of the skin.

In 1882, Goldscheider[12] describes a phenomenon which he later refers to as an after-sensation. "Wenn man nämlich mit einer Messerspitze schnell, am besten die Hohlhand berührt, so tritt momentan nur die Tastempfindung auf, welcher dann erst der stechende Schmerz folgt. Dasselbe kann man bei einem leichten Schlage mit der flachen Messerklinge wahrnehmen."

In the same paper Goldscheider also mentions the long after-sensation of the tickle feeling which in diminishing loses its characteristic quality and assumes that of a single contact feeling. In 1884, he again speaks of the long after-sensations of tickle which go off in a "breath-like" contact. In that same year and again in the following, he states that if a part of the skin be stroked lightly so as to produce an after-sensation of tickle and a moderate pressure stimulus be then given in the center of this region it will cause the tickle feeling to disappear. In a similar way these after-sensations can be stopped by rubbing the stimulated spot—i.e. by a further arousal of the touch nerves.

In 1882,[12] Goldscheider describes the after-sensations of temperature and most of his papers for the next four years contain some reference thereto. No effort is made to report these references in order. The excitations of temperature nerves are, he says, revealed through their long after-sensation. This is true for both warm and cold stimuli although cold are especially favorable. In connection with his description of temperature points he states that the temperature sensations obtained there, do not disappear with the cessation of the stimulus but have an after-duration which shades off into an indefinite, indescribable feeling. This phenomenon is very insignificant in some regions and overwhelmingly distinct in others. From continued pressure on a temperature spot the temperature sensation may persist for a long time and on especially favored spots leave behind it a clear after-sensation. This phenomenon is, however, rare. As an explanation of the process he says "Allein diese Nachempfindung muss Ich für einen rein nervösen Vorgang halten, der mit der objectiven Temperatur der Hautstelle nichts zu thun hat". And this is proved by the fact that a momentary contact with an object only moderately cool will give so intense and prolonged an after-sensation that it cannot be due to any objective cooling of the skin, and also by the fact that temperature after-sensations can be produced by mechanical stimuli.

Goldscheider, in 1885,[13] makes a brief reference to the after-sensations of pressure, saying that on certain regions of the body, notably the back and thighs, there are many pressure spots whose after-sensations are so vivid as to obscure the perception of new pressure spots when stimulated.

Blix,[1] in 1884, noticed the persistence of pressure after cessation of the stimulus: :"Dazu kommt, dass der sichtbar statische Zustand, welcher durch einen andauernden Druck auf die Haut eintritt, daselbst eine ebenfalls andauernde Druckempfindung zu Stande bringt, während die Nervenfaden nur bei denn ersten Eintreten des Drucks auf sie gereizt werden".

In 1885, Dr. Donaldson,[5] in his paper "On the Temperature Sense," remarks this phenomenon as follows: "It was of course noticed with these spots (cold), as with the whole skin, that the thermal sensation when roused lasted some time after the removal of the stimulus, in some cases several minutes. This is often a disturbing element in certain experiments, for it is not always clear whether a given sensation comes from the spot at which the stimulus is acting, or from the spot at which it just acted. It is this fact which contributes largely to the continuity of the sensation of temperature when a stimulating body is drawn over the surface of the skin." This after-effect, he agrees with Goldscheider, is a purely nervous phenomenon quite independent of any objective change of temperature.

In the same year, Dr. Donaldson in collaboration with Professor G. Stanley Hall[6] published the results of certain experiments on the cutaneous perception of movement. Here they found cases where the sensory after-image of a moving point fades in consciousness very slowly. In a test on varying the rate of movement, or the distance which must be traversed before the judgment is made, these authors state that "Down to the lower limit of velocity here used (1cm. covered in .012″) it would seem that the after-image of the sensation caused by the moving point, from the beginning, persisted in consciousness as vividly, or at least as effectively, for 40″ as it does for 4/10 of 1″, or else that the two were judged in different ways". This is interesting as indicating the duration of the persisting sensation.

In 1887, Victor Urbantschitsch[36] in a clinical investigation of the sensitivity of parts of the face inflamed from an ear disease, describes the appearance of tactual after-sensations; and in the same paper reports certain observations made on temperature after-sensations with normal subjects. These tactual stimulations were given with a sharp-pointed instrument, but their after-sensations can, he states, be easily obtained by pressure from a blunt point or by light stroking of the skin. These cutaneous phenomena show the primary and secondary phases common to vision. "Das Nachbild schliesst sicht einerseits unmittelbar dem vorausgegangen Sinnes-eindruck an und bildet mit diesem eine gemeinsame ununterbrochen Sinnesempfindungen, oder das Nachbild taucht anderseits nach einer vorausgegangenen Empfindungspause wieder auf und verschwindet nach einer individuell verschieden langen Zeit, um vielleicht noch ein, 2 und 3 mal wiederzukehren." Both types may appear in a given experiment, or either may appear alone. The secondary after-sensations proved too erratic to be used as a test of the relative sensitivity of the diseased and normal parts, but the primary were found to be quite consistent and afforded a very good test of cutaneous sensibility. It was learned in this connection that there were six cases where the primary after-sensation was of longer duration on the normal than on the inflamed side as opposed to one where the conditions were reversed. This difference in duration tended to be equalized as the patient recovered. By application on the forehead of cold and warm metal surfaces, after-sensations were obtained which either (1) disappeared instantly, returned weakly after 15-25″, gradually grew stronger and remained so 33-60″;

or (2) persisted after the removal of the stimulus 35-50″, returned after a latent period of 12-23″ and then remained 4-25″. Essentially the same results were obtained from touch stimulations on the normal skin, except that the secondary after-sensations were more numerous. For example, after a touch stimulation a primary after-sensation was felt followed by a latent interval of 12″, then a secondary after-sensation of 2″, latent interval 16″, after-sensation 10″, latent interval 72″, after-sensation 16″, latent interval 15″, after-sensation 37″, latent interval 10″, after-sensation 30″, latent interval 15″, after-sensation 13″, latent interval 17″, after-sensation 65″.

In 1890, Goldscheider published an experimental paper dealing exclusively with the subject of the cutaneous after-sensations obtained from mechanical and electrical stimuli, together with his physiological explanation of the process. A year later, he repeated and amplified this research in collaboration with Professor J. Gad,[14] and this later work is the most elaborate and systematic treatment of the subject to be found in the literature. The first paper is but a brief outline of the other and, as it contains nothing of importance not contained in the second, it will not be treated separately in this survey.

This paper, published in 1891, begins with that familiar description of a cutaneous after-sensation. "Uebt man mit einer Nadelspitze einen leichten Eindruck auf die Haut aus, so hat man ausser der ersten sofort eintretenden stechenden Empfindung nach einem empfindungslosen Intervall eine zweite, gleichfalls stechende Empfindung, welche sich in ihrem Charakter dadurch von der ersten unterscheidet, dass ihr nichts von Tastempfindung beigemischt ist, sie vielmehr gleichsam wie von innen zu kommen scheint." This phenomenon will appear likewise with very weak stimuli, even with those lying close to the threshold. With stimuli intense, but not painfully so, the secondary sensation may be painful; but if the stimulus *is* painful, the secondary sensation is weaker than the primary and appears less clearly, the latent interval being partly filled up by the persistence of the primary. The stimulation for these after-sensations can be given equally well by a dull point. This phenomenon, Goldscheider specificly identifies with the one quoted above, where by the prick of a knife blade a touch sensation appeared, followed by a pricking pain.

The after-sensations obtained from electric stimulation are first described. These stimulations were given by means of an induction current rhythmically interrupted at certain intervals so as to form a series of similar stimuli separated by equal intervals. These series were varied as regards the number of induction shocks given in a series, the length of the interval separating them, and the intensity of the stimulus. The intervals varied from 10-200 $\sigma$, and to obtain such there was introduced into the primary circuit a tuning-fork oscillating 100 times a second (thus giving 10 $\sigma$ intervals) and a fast and a slow-swinging electro-magnetic hammer which cared for the intervals of 16-200$\sigma$. A few experiments were made on one subject with intervals of 300-950$\sigma$ and for these a metronome was used. To vary the length of the stimulus-series and hence the number of induction shocks given, three appliances were used, descriptions of which can be found in the paper mentioned. The intensity of the electric current was easily varied by the sliding up and down of the secondary coil. The electrodes were enclosed, at a distance of 1 mm., in a rounded hand-grip of wood which the subject held, pressed against a constant spot on the palm of the hand. The duration of the latent period was measured by means of Pfeil chronographs and a Beiss contact-maker.

The general results of the experiments may be stated briefly as follows: "Für die Erklärung des Phänomens der secondären Empfindung ist nun von grundlegender Bedeutung, dass dieselbe vollkommen fehlt, wenn ein einzelner Oeffnungsschlag auf die Haut applicirt wird, dagegen durch eine Reihe solcher Reize hervorgebracht wird. Ein einzelner Oeffnungsschlag giebt an denselben Hautstellen, an welchen man das beschriebene Phänomen mit der Nadel sicher erzeugen kann, nur eine primäre Empfindung und zwar im ganzen Bereich der Reitzstärken ein, vom Schwellenwerth bis zum Auftreten excentrischer Empfindungen. . . . Lässt man jedoch mehrere Inductionsschläge auf einander folgen, so tritt, durch ein leeres Intervall getrennt, die secondäre Empfindung ein, welche im Allgemeinen denselben Charakter hat wie die primäre, nur mit dem Unterschiede, dass sie nichts discontinuirlich ist."

All gradations of secondary sensations were obtained, from those just noticeable to those which were very strong and clear, and from those preceded by a clear latent interval to those in which the secondary sensation was continuous with the primary. This variation of quality and intensity was directly dependent upon the conditions of stimulation. There were certain individual differences, and even in the same individual, under identical conditions, the results sometimes vary, but these variations are unimportant and commonly found in all subjective phenomena. As has been stated, a single induction shock produces only a primary sensation. Two shocks may, however, call out the secondary sensation but in a "sehr undeutlicher und inconstanter Weise", and three stimuli give similar results. Four stimuli, on the contrary, will produce the phenomenon with great clearness, provided the intervals be of the proper length (30-60 $\sigma$); but with intervals above or below this length, the secondary sensation becomes progressively less clear. These conditions hold likewise for five, six, and seven stimuli; but by further increase of the number of shocks the interval must be constantly shortened to obtain the best results. So, in general, it may be said that if the length of the interval is increased the number of stimuli must be decreased, and if the number of stimuli is increased the interval must be shortened. To cite extreme examples, 3 stimuli require an interval of 190-200 $\sigma$ to produce the secondary sensation clearly, while with 40 stimuli a 10 $\sigma$ interval is sufficient to make the secondary sensation appear distinctly. This reciprocal relation applies best, however, to the middle regions and is only generally applicable to such extreme cases as those just mentioned, although it may be generally stated that the *total duration* of the series remains approximately the same throughout, secondary sensations being obtained by 50 stimuli with 10 $\sigma$ intervals and by two stimuli with an interval of 620 $\sigma$. The facts most noticeably brought out in this connection, however, indicate that there is a mid-region, both of stimulus-number and stimulus-interval, within which the after-sensation is most marked and that "Dieses Feld zieht sich aber sowohl nach unter wie nach oben spitz aus".

With regard to the effect of the intensity of the stimulus on the appearance and clearness of the after-sensations, it may be said in general that a moderate intensity is most favorable, although it is very difficult to give any exact figures on account of the increase in intensity of a stimulus when it is applied in series. The most favorable intensity was, therefore, empirically determined in each case. It was found that by decreasing, and especially by increasing, this intensity the secondary phenomena became less clear.

It appeared in the course of the experiment that certain regions, varying with the two subjects, were more favorable than others for producing the phenomena in question,—the volar side of the hand and wrist, for example, being more suitable than the dorsal,—and this is attributed to the local sensitivity of the skin, because on these spots, also, the primary sensation was sensed more clearly.

The quality of the after-sensation obtained under the best conditions is described as "ein schnell auftauchendes und kurz dauerndes fein-stechendes Gefühl von nicht schmerzhaftem Charakter." With too strong intensity the sensation may irradiate and this irradiation have a "tickle" quality. With a small number of stimuli (2-3), likewise, the sensation tends to spread. Again, under certain conditions, the after-sensations lose their pricking and quick-disappearing quality and persist for a long time as a tingling, burning sensation. The qualitative changes may be further described as follows: "Bei einer noch mässigen Reizzahl, etwa 10 Reizen zu 40$\sigma$ Intervall, beginnt die secundäre Empfindung stechend, wird aber statt abzufallen schneidend. Bei grösserer Reizzahl bez. Vermehrung der Reizstärke, beginnt sie gleich schneidend. Bei noch weiterer Vermehrung der Reizzahl, besonders wenn gleichzeitig die Gesammtdauer der Reizreihe vergrössert wird, ist sie nicht mehr durch ein leeres Intervall von der primären Empfindung abgesetzt, sondern schliesst sich unmittelbar an diese als eine schneidende, langgezogene, allmälig abklingende Empfindung an."

In general, it was found that the time which elapsed between the end of the stimulus-series and the appearance of the secondary sensation was nine-tenths of a second. This time was found to be approximately constant as long as the stimuli were given within the limits of what is termed the "Auslösungswerte", i. e. those conditions of stimulation which will produce the secondary phenomena most clearly and easily. That is to say, the number of stimuli may be three or fifteen, the interval 10$\sigma$ or 70$\sigma$, (and the total duration of the series 30$\sigma$ or 370$\sigma$), but the space between the end of the series and the beginning of the after-sensation will remain the same except for certain irrelevant fluctuations. If, however, the boundaries of the "Auslösungswerte" are overstepped the secondary sensation makes its appearance independent of the duration of the stimulus but at its old "time-moment", i.e., the interval is correspondingly shortened. If the duration is still further extended,—to 800$\sigma$ or over,—the secondary sensation flows into the primary, or does not appear at all.

As an apparatus for applying the mechanical stimuli so as to vary their intensity, duration, and "abruptness" of application and withdrawal, the following arrangement was used. A sort of Marey tambour, operated by a handle, contains a needle fastened perpendicularly to the membrane and this is connected by tubing with a second tambour which registers the curve, while a time-curve is written below. The intensity of the stimulus is thus a function of the ordinate value and the abruptness of application, as well as the entire duration of the stimulus, is given in terms of the abscissa. For the more intense stimuli this apparatus was found too frail and another was constructed. This consisted of a spiral spring, to one end of which a needle was fastened. Inside the spiral of the spring there was a glass tube one end of which was connected with a Marey tambour, the other being covered by a membrane against which the head of a needle rested lightly when the spring was not in action.

The record of the results here obtained is obscure and it is necessary to turn to the shorter paper for a clear statement. It appears, however, that with mechanical, as with electrical stimulation, there is a certain range of optimal conditions within which any change of intensity, duration, or abruptness is without significant effect upon the latent interval. The intensity might vary from an ordinate height of .5-2 mm. (with the stronger stimulus apparatus) and from 3.5-8 (with the weaker), without any appreciable change in the latent interval. With stronger stimuli, however, it became shorter. By varying the abruptness of application, it developed that if the interval were measured from the *beginning* of the stimulus to the appearance of the secondary sensation the time was somewhat shortened, but by measuring from the *end* it remained about the same. The varying durations of the stimuli gave approximately equal results unless the duration exceeded 500$\sigma$, in which case the interval was lessened. It is significant that with optimal conditions the latent time is practically the same as that obtained by electric stimulation. The length of the latent interval seems to be influenced to quite an extent by the clearness of the secondary phenomena. When the stimulation is given on the volar side of the wrist—an especially favorable spot—the empty interval is much shorter; and on the sole of the foot it is increased by 400-500$\sigma$ beyond its duration on the palm of the hand.

The last third of the paper is devoted to an explanation of the phenomenon. Goldscheider maintains that it is without doubt a summation process. This summation takes place in those cells of the grey matter which come into relation with the fibers or collaterals of the spinal root fibers ascending in the posterior columns. With a single induction shock the excitation which reaches these cells is not sufficient to "break through" to a conscious center, but is instead stored up in these cells, until, by a series of successive stimuli, the process of continual storing up results in a changed condition which causes the cells to "unload" their energy; and this cellular excitation breaks through to the center by a path of its own. This is termed the Summation Path. The primary sensation is in every case the result of an immediate conduction through the posterior columns and is therefore responsive to even a single stimulus. This Summation Path is identified with the Pain Path of earlier authors, and the pain of a primary sensation is explained by saying that a stimulus of great intensity is able immediately to break through the Summation Path. This identification is supported by clinical cases of spinal-cord disease where a series of non-painful stimuli result suddenly in pain, i.e. in a new sensation. A close analogy is likewise drawn between this phenomenon and that of delayed pain under pathological conditions. Schiff, Funke, and Wundt are quoted as the authority for locating this summation phenomenon in the posterior horn, and the pathological finding of analgesia in gliose favor this localization. In order to explain the appearance of a secondary sensation by a single mechanical stimulus, under such a summation hypothesis, the idea is advanced that a mechanical stimulus must in itself be looked upon as a *series* of stimuli. The justification for such an explanation is given in the following paragraph which is the only discussion of the matter. "Bezüglich der mechanischen Hautreize hat sich das bemerkenswerte Ergebniss herausgestellt, dass dieselben in ihrer Wrikung niemals einem einfachen Reiz, sondern stets einer Reihe von Reizen entsprechen. Dies bleibt bestehen, unabhängig davon, ob unsere Auffassung von der Summation richtig ist oder nicht. Die Vergleichbarkeit des mechanischen Reizes mit der Reizreihe ging so weit, dass auch die Beziehungen des Auslösungswertes zum Zeitpunkte der secondären Empfindung und zur Art und Dauer der Reizwirkung sich als ähnliche herausstellten."

In 1892, Max Dessoir,[4] in a monograph on the skin sensations, devotes a page or two to the after-sensations of temperature. In speaking of the cutaneous after-sensations in general he states that they are of two sorts, those which are uninterrupted, which follow the stimulus without a break, and those which make their appearance after a short sensationless pause; and these two kinds he designates by the terms Continuous and Intermittent.

In his experimentation on the temperature after-sensations he obtained the following data; "Das Nachbild eines Kälte—oder Wärme—Reizes wird durch die entgegengesetzte Erregung aufgehoben, durch eine neue gleichartige Erregung verstärkt". For example on withdrawing the finger from cold quicksilver the persistence of the cold sensation is noticeable for some time; if however, immediately on the withdrawal, the finger is plunged into *warm* quicksilver, the cold immediately vanishes and the thermal sensation becomes neutral, but when the finger is again brought out into the air the cold sensation reappears as though entirely uninterrupted. In this experiment the average duration of this persistence was 534$\sigma$ and the phenomena were not observable in the neighborhood of the threshold,—that region tending rather to produce Intermittent after-sensations.

The Intermittent after-sensation he states has been observed in the fields of optics and acoustics and by Goldscheider, in the cutaneous realm. This Goldscheider phenomenon should not, however, be identified with the other two for the touch after-sensation only makes its appearance after a *series* of stimulations. This same dependence on a serial stimulation is to be found likewise with the temperature sense, for this after-sensation makes its appearance most clearly if 4 very light temperature stimuli (of .5″ duration) are allowed to fall on the same spot. One can then clearly differentiate the primary sensation, a sensationless interval of about a second, and then the secondary sensation. With the application of stronger stimuli this fluctuating phenomenon does not appear, but, on the spot stimulated there immediately comes a steady after-image joined to the stimulus sensation. To determine the duration of this after-sensation a "Sensibilometer" was used. This consisted of a metal cylinder, 1 cm. in diameter, heated for 15″ in quicksilver of 50-55° C. and then placed on the skin of the back of the hand and on the pulse of the left radial artery. On sensing the warmth the subject turns on a chronoscope and the experimenter at the sound immediately removes the cylinder; with the cessation of the resulting after-sensation the subject turns off the drum. From this total time the author desires to subtract the time necessary for the auditory reaction of the experimenter as during this time the stimulus was still applied. For this purpose he assumes the average time-reaction of 138$\sigma$ obtained by Jastrow in his Time Relations of Mental Phenomena, subtracts this from the total time and calls the remainder the duration of the after-sensation. With the one subject tested the duration (exclusive of the auditory-reaction-time) varied from 316-807$\sigma$. If the temperature of the stimulus was so intense as to produce pain, this time increased to 1513-1889$\sigma$.

Ladd,[22] in his Physiological Psychology, published in 1891, speaks of the temperature after-sensations as follows: "After-sensations of temperature seem to exist. But when a surface of the skin has been warmed or cooled and the after-image has faded quite away, it is said that it can be called back by light mechanical irritation; this is especially true of sensations of cold."

Wundt,[39] in a note in the 4th edition (1893) of his Grundzüge [omitted in the 5th edition] cites Goldscheider's secondary phenomena and says of it: "Es ist nicht unwahrscheinlich, dass es sich hier um eine durch die Doppelheit der sensibeln Leitung bedingte Erscheinung handelt, wobei die primäre Empfindung durch die directe, die secundäre durch die den Umweg über die graue Substanz einschlagende Leitung vermittelt wird, um dieselben Bedingungen also, die der verschiedenen Leitungsgeschwindigkeit von Tast und von Schmerzreizen zu Grunde liegen". In the 5th edition of this work (1902) he records (1) von Frey's persistence of pressure after skin deformation and, (2) the persistence of a cold sensation after removal of the stimulus.

Külpe,[21] (1893) in his Outlines, makes several references to the phenomena of cutaneous after-sensations. Goldscheider's research is cited together with his physiological explanation of the same: "but these after-sensations of pressure would seem to appear only under very special conditions, hardly realized by normal stimulation".

"After-sensations of heat have been observed, of a kind similar to those of pressure. The blank interval between primary and secondary sensation amounted to about 1 sec. It is, therefore, conjectured that the thermal excitation also undergoes dispersion into the gray substance of the cord and that there summation and retardation of stimulation take place." . . . "The effects of temperature stimuli may persist for a certain time, but always (so far as we know) in the quality of the original sensation."

On page 85, he mentions the discovery of sensory nerve fibers with centrifugal conduction which have been found in the optic and "may be presumed to exist in all sensory nerve trunks". And of the connection of this discovery with the phenomena of after-sensations he says: "It has been noticed, in almost all the sense departments, that a brief stimulation of the peripheral organ gives (a) a 'primary' sensation, (b) then a short pause, occupying a fraction of a second, and (c) finally, a 'secondary' sensation, of the same quality as the other. The succession becomes readily intelligible, if we conceive of the first, centripetal excitation, as arousing a second, centrifugal. We have no need of the special hypothesis proposed for the sense of pressure" (Goldscheider's).

In 1893, Dresslar,[7] in a paper on the Psychology of Touch, takes the precaution to change the region of stimulation and to allow sufficient time to elapse between successive applications "in order that the after-sensations shall be as little confusing as possible". And at the end of his paper he devotes a little space to the consideration of these *per se*. In order to test Goldscheider's results he asked a number of his students to touch the skin repeatedly with small cork pencils and to note the resulting sensation. The following are examples of the results obtained. A more or less ticklish sensation at first appeared, some time after, when it was supposed that all sensation had gone, a sharp somewhat painful sensation flashed out and disappeared nearly as suddenly; after quite a period of time it again appeared but with less force. After stimulation, in addition to the feeling of contact, in about one half the cases, there came a distinct secondary sensation of a more or less painful character, and diffused over a greater area than the primary sensation. In cases where the primary sensation was somewhat painful the after-sensation did not come out so clearly. After touching the back of the hand there arose as an after effect a slight drawing sensation. After a slightly painful stimulation a sharp fine sensation appeared later which was located somewhat nearer the wrist. With a light pressure the sensation was a more persistent one of a sticking quality which faded slowly with several recurrences. These examples were typical of all the rest. The after-images of touch could, he said, be facilitated if the surface be stimulated by tickling, in order to increase the blood supply in that region, and this facilitation could not be assigned to a generally increased sensitivity to touch, for, under these conditions, the primary sensations were unaltered. In addition, it was noted that the appearance of the after-sensation was coincident with the return of blood to the spot stimulated and "this rush of blood is the chief and, as far as I can distinguish, the only direct stimulating agent for the production of this after-sensation". Goldscheider's summation theory he therefore considers needlessly difficult.

In 1893, Krohn,[20] in a paper on the Simultaneous Stimulations of Touch, says of the after-images of touch that they are often more clearly felt and localized than the original stimulus—the subjects sometimes correcting their localizations by the "dawning of images". These after-sensations are more lasting in some localities than in others, the hairy portions, especially when shaved, being very favorable. The regions in which the after-sensations are especially intense and distinct would be graded as follows—calf of leg (behind), ankle-bone (outside), shins, nipples, instep and tendons. The duration of the after-sensation on the calf of the leg amounted, in some cases, to 5 minutes.

Pillsbury (1894)[27] in connection with his investigations on cutaneous sensibility, says that only one experiment was made on each skin area during a series "as it was found that the after-effect of pressure exercised a disturbing influence upon the judgment. Before this precaution was taken it was often noticed that the after-effect of the preceding experiment was mistaken for the impression given to be localized, or at least gave rise to a confusion."

Henri (1896)[17] in his experiments on skin localization, states that it is necessary to take account of two types of response. The first of which is where the contact produced by the experimenter has not completely disappeared, and in this case the subject guides himself throughout by that trace and seeks to touch the spot where he still feels a faint contact.

Parrish (1895)[25] in a series of similar experiments, says that "not more than 10 experiments were made at a sitting and thus the after-effects of pressure were eliminated".

In his paper of 1896, von Frey[8] noticed, in connection with a determination of the pressure threshold, that in some cases where the application and the continuance of the stimulus was distinctly perceived its removal was unnoticeable. "Uebrigens kommt es unter diesen Umständen auch vor, dass die Wegnahme gar nicht bemerkt wird und die Empfindung des vollen Druckes, nur ganz allmählich abnehmend, den Reiz für längere oder kürzere Zeit überdauert", . . . "Nun ist bekannt, dass eine längere Zeit dauernder, nicht zu schwacher Druck auf der Haut ein Abbild des drückenden Körpers hinterlässt oder ein Druckbild, wie man es nennen könnte." And this pressure after-image is erroneously considered a continuation of the stimulus. The explanation of this phenomenon is to be sought in a certain "after-working" of the nervous process conditioning the pressure sensation. This "after working" and its consequent pressure image are further dependent on the rapidity with which the skin is restored from the depression caused by the pressure stimulus. This is shown by the fact that this persistent after-pressure is not produced by weights of minimal intensity, i.e. those too light or too briefly applied to cause a deformation of the skin. The common illusion of the coin pressed upon the forehead is cited as analogous here, for although temperature after-images may be active in such a case the same results may be obtained with cork or wooden objects having a neutral temperature. In a later paper (1899), written in collaboration with Kiesow,[9] it is again stated that after strong and not too brief weighting of the skin the sensation outlasts the outer stimulus and this is again attributed to a "rückständige Deformation,—ein sog. Druck-bild auf der Haut".

In the first mentioned paper there is described the phenomenon of a pressure sensation and a later pain sensation arising as the result of a single stimulus; and Goldscheider's similar observations are cited but the phenomenon is given a wholly different explanation. Goldscheider's conception of the pain sensation as a summation of pressure stimuli is refuted by the following results obtained: (1) On pain-free pressure points the painful after-sensation fails to appear; (2) On pain spots situated in the neighborhood of pressure spots the phenomena occurs in the manner described by Goldscheider; (3) On isolated pain spots the accompanying pressure sensation is absent, while the painful after-sensation appears clearly. Goldscheider's experiments tend, therefore, rather to show the dissimilar manner of response of the two forms of nervous apparatus to the same stimulus. Von Frey's own explanation is based on the hypothesis of separate end-organs for pressure and pain, the latter having a higher threshold of response, especially for weak stimuli, and a great inertia especially for oscillatory stimuli, which assumes the form of a "Nachhinkens" and has been erroneously considered a secondary sensation.

In 1896, Kiesow[18] confirmed von Frey's results on the after-persistence of pressure. "Il semble donc que chaque fois qu'une charge est suffisamment grande, on qu'elle reste assez longtemps pour produire une deformation sur la peau, la sensation survit le stimulus."

In 1897,[23] Lay, in connection with a discussion of Mental Imagery, states that he has himself experienced "what might be called tactual after-images".

In 1897, there appeared a brief paper by F. N. Spindler[32] on the After-Sensations of Touch. These after-sensations of touch, or more properly pressure, are very difficult to obtain, by reason of their tendency "to mingle with the general and common muscular and organic feelings". While, he says, these after-illusions may occur they could never be mistaken for actual tactual stimulation if subjected to a careful analysis. The after-sensation is at best vague, indefinite, and irregular and hard to distinguish from the subjective sensations which arise when the attention is directed to a particular skin-spot. In his introduction he specially states that he intends dealing not with the secondary sensations succeeding a sensationless interval, but "with those varying sensations which follow the cessation of a more or less prolonged stimulation of the skin by means of pressure". (Evidently those after-sensations which elsewhere have been distinguished as Primary.) In one of his tables, however, he records the "interval between the end of the stimulation and the appearance of the after-sensation". An interval which always occurs and has an average duration of 36.5″. (It would seem, therefore, that he is treating of those secondary sensations which make their appearance unpreceded by a primary after-sensation, and this appears probable in view of the very long stimulations given.)

The method of stimulation consisted of weights varying from 25-1000 grs. placed upon a holder having a base of 7/8 of an inch, and applied to the back of the hand for intervals varying from 5″-10′. The following results were obtained from his experiments.

(1) The briefest duration of stimulation which would give rise to an after-sensation was 5″, the weight in this case being one of 150 grs. (2) There appeared to be little relation, either between the duration of the stimulation and the length of the "interval", or between the length of stimulation and the duration of the after-sensation. (a) The interval seemed to increase up to a stimulation of 3′ duration and then, decreasing slightly, remain about the same. (b) With stimulations of from 1-3′ the duration of the after-sensation is about 5′, while a 5-10′ stimulation gives about a 10′ after-sensation. (3) The effect of different weights on the duration of the after-sensation seems to indicate that weights of 150-500 grs. give the best results, and that 1000 grs. always give shorter after-sensations than those obtained by 500 grs. (4) The quality of the after-sensations is described by the author, in his own case, as simply a feeling of skin contraction, as if the surface were painted with collodion or mucilage, but other subjects obtained more varied results such as touch and temperature sensations, itch, a sort of external smarting, and a deep dull ache.

In 1898, Vintschgau and Durig,[38] in the course of an investigation of the least noticeable interval between two successive electrical skin-stimuli, chanced upon a contradiction of Goldscheider's hypothesis that a secondary sensation is not to be obtained from a single induction shock. It was found that with a single induction shock the subject frequently got beside the first sensation a second, sometimes stronger, sometimes weaker, or again of equal intensity with the first. Frequently the location was changed, the second sensation appearing to the right or left of the first. This phenomenon would appear to be identical with Goldscheider's secondary sensation, the description of which the authors quote at some length. To prove that this difference was a function, neither of the strength of the stimulus, nor of the region tested, nor of the construction of the electrode the intensity of the stimulus was varied through many gradations, and the stimulations were given on the same skin areas used by Goldscheider and Gad and with a similar electrode. A secondary sensation was under these conditions frequently obtained by a single shock.

Sanford,[30] in his Manual (1898), records the after-sensations of touch, i. e. Goldscheider's phenomena, and interprets the same by Goldscheider's explanation. He mentions also the temperature after-sensations, both continuous and intermittent,—all being, however, of the same quality as the stimulus—and the long after-effect of tickle.

In 1898, Crawford,[3] in a study of the Temperature Sense, criticises Donaldson's method of locating hot and cold spots by drawing the stimulating point along the skin on the ground that it gives rise to after-sensations.

Clark[2] (1898) in a paper on the Sensations of Pressure, states that "the sensation may outlast the stimulus, probably as the result of the deformation of the skin which lasts for some time". Later, in connection with his tabular results, he quotes the introspection of one subject: "Pressure rather strong, soon diminishing, after 20″ apparently gone, then again perceived, finally definitely vanishing," but makes no comment on the same.

Titchener,[34] in his Instructor's Manual (1901), records Goldscheider's after-touch phenomena but accepts von Frey's explanation of the same. Later, he speaks of the pressure after-sensation varying with different observers, and being recalled, after its disappearance, by a second stimulation.

In 1902, there appeared a paper by Torsten Thunberg[35] in which is described the phenomenon of two "stechenden" sensations resulting, under certain conditions, from a single thermal, mechanical, or electric skin stimulation. Thunberg quotes at some length the results of Goldscheider and Gad and comments critically upon their identification of the phenomenon noticed by Goldscheider in 1882 (where a touch sensation is followed by a stinging pain), with this later one (which consists in a stinging sensation followed, after an interval, by a second similar one). In opposition to Goldscheider's hypothesis of the same nerve serving for pain and pressure, on which he bases his explanation, the author quotes von Frey's more recent theory that there exist separate nerves and nerve-endings for these two sensation qualities, and that the delayed pain sensation, which is what Goldscheider was probably describing in his early paper—is due to the greater inertia of the pain spots. Von Frey's theory, while it explains the first case would not, he contends, apply to the other phenomena described by Goldscheider and Gad, where the primary and secondary sensations were similar and neither was painful. It is with this double "stinging" sensation of Goldscheider's that Thunberg is concerned in the present investigation. These sensations are best described by the adjective "stechende", and they contain no painful nor unpleasant feeling tone. They can be called out by weak mechanical (needle-prick), thermal, or electric stimuli; while with a greater intensity of these stimuli the sensation will change to one of pricking, burning pain. These two sensations then, one "stechende" and indifferently toned, and the other nearly identical in quality but having a distinctly painful tone are mediated by the same nerves (pain nerves) and correspond simply to differences in the intensity of the stimulation.

Two methods of thermal stimulation were used, one providing for differences in intensity with the duration of application remaining constant, while the other had a constant intensity and could be applied for different lengths of time. The first consisted in the application of what he terms "Reiz-lamellae", and these were flat plates of metal 4 cm. square and varying in thickness 10-150$\mu$. They were taken from boiling water and placed on the skin, and the amount of heat given off was measured in terms of the thickness of the Reiz-lamellae. The second apparatus—which is spoken of as a "Temperator"—consisted of a hollow metal vessel with a rounded surface 3 cm. in diameter, through which water of a given temperature flowed in a continuous stream so that the temperature of the vessel remains constant. The results obtained by this first method are best given in his own words. "Die schwächsten Reize ein einzige schwache Empfindung stechenden Charakters entstehen lassen, die bei erhöhter Reizintensität an Stärke zunimmt. Die Empfindung hat eine ziemlich lange Apperceptionzeit. Wird nun die Stärke des Reizmittels noch weiter erhöht, so erhält man zwei derartige Empfindungen, eine schnell sich einstellende und eine mit längerer Apperceptionzeit. Die erstere ist die schwächste, schwächer sogar als die, die als einzige bei etwas gegeringerer Reizstärke erhalten wird. Wird die Reizintensität noch mehr erhöht, so werden beide stärker, ziehen sich in die Länge und fliessen schliesslich zusammen. Schon hieraus scheint sich zu ergeben, dass die bei schwacher Reizung allein auftretende Schmerzsensation dem zweiten der beiden bei stärkerer Reizung auftretenden "Stiche" entspricht. Der erste scheint sich vor dem bereits bestehenden einzuschieben." By the second method it was found that—(1) With long application, i.e. when the Temperator was held against the skin until a pain sensation was felt, there appeared, with water of 50°C, a fine "sting" which lasted a very brief time and then vanished completely. With stronger stimuli this "stinging" became stronger and more lasting. There was, however, no secondary sensation. With the water raised to 56-57°C, a weak "stechende" sensation was obtained which swelled directly into an abrupt, quite strong pain, but there was no repetition of the same. (2) If, with water of 58-60°C the Temperator was raised the instant one began to feel the "stinging" sensation, a very brief sensationless interval was perhaps perceived, followed by a second "stechende" sensation. With 60°C, the only indication of the double sensation was that the pain which appeared began somewhat weak and increased abruptly. (3) With brief contact, where the instrument was raised before the "stinging" sensation appeared, the double pain sensation was easily called out with temperatures above 60°C, provided the time of contact was suitable. With too brief applications, no pain sensation or only a single one was called out, or if the stimulus endured too long, the strength of the pain was lessened and the "Zwischenzeit" diminished or disappeared entirely. These experiments were performed on different persons and on different parts of the body to preclude the objection that the phenomenon was due to some local or individual peculiarity. To measure the apperception-time for warm sensations of different intensities, a simple apparatus was used, consisting of two fine parallel wires stretched across the skin, through which is passed a current too weak to be conducted by the skin. With the application of the metal temperature stimulator the circuit is closed and with its removal is broken again at the moment when the sensation is perceived. The majority of his results in this connection are not of importance for this study, but it is stated that on the average the length of the "Zwischenzeit" is .87 of a second, and that this interval is quite constant.

The appearance of two "stechende" sensations with punctiform and areal mechanical stimuli was next investigated. For areal mechanical stimulation the following apparatus was used. A steel spring was set up having one end fastened to a block and the other lying free and bearing on its tip a flat plate. By raising the free end to any determined height and then releasing it in a uniform manner any intensity of stimulus may be given. With increasingly intense stimuli one gets the following corresponding sensations: (1) pure contact; (2) contact which after an interval is followed by pain; (3) momentary and delayed pain sensations; (4) with still stronger stimuli, the later-appearing sensation becomes weaker until only one strong momentary sensation appears.

For punctiform stimuli an entirely different apparatus was used. A fine-pointed needle was hung by a thread to the upper arm of a pair of forceps. By pressing on the spring of the forceps the needle would be forced against the skin and as soon as the pressure ceased would be lifted again by the power of the spring. To prevent lateral oscillation the needle moved up and down in a glass tube. The changes in intensity were brought about by means of a cross-bar the longer end of which rested on the needle and upon this bar weights of different sizes were hung. The dorsal side of the hand was used, and the results obtained varied, on different points of the skin, in the following manner. (1) There were certain spots on which only a contact sensation appeared regardless of the intensity of the stimulus. (2) On some spots there appeared a contact feeling followed after a sensationless interval by a "stechende" sensation; with stronger stimulation on these spots the contact feeling was covered up by a "stinging" sensation which was followed as before by a second similar one. (3) On other points, with weak stimuli, the same results were obtained as in 1, while by increasing the stimulus, a stinging sensation replaced the contact but the secondary sensation was lacking. (4) On still other points, the results are in general the same as in 2 but here the stimulus must be very intense in order to obtain the stinging sensation. The early and late pain sensations are therefore only called out on certain points—von Frey's pain points. The early and late "stinging" sensations are not exactly alike, for aside from the fact that the early "stinging" sensation is usually mixed with contact, the late sensation is "auch nicht so momentan und hat einen Charakter, von dem ich, um ihr zu verdentlichen, sagen möchte, dass er voller ist als der der augenblicklichen".

To measure the reaction times of these sensations a slight modification was made in the punctiform apparatus. A small metal plate was arranged in such a way that the head of the needle would come in contact with it when rising from the skin. Both this plate and the needle were connected with a battery by fine wires so that by their contact the circuit was established. The exact application of the devise is not stated; but the results obtained show that the average reaction-time for the first contact was .21″ and for the late "stinging" sensation .88″; for the early "stinging" sensation .18″ and for the second "stinging" sensation .96″. This corresponds to the time for the early and late "stinging" sensations aroused by thermal stimuli. The number of tests taken in this connection were not numerous, but the author regards them as conclusive.

With electric stimuli especial attention was given to the effect of brief contact and of extremely punctiform stimulation, i.e. with a finer electrode than was used by Goldscheider. The mechanical-punctiform apparatus was used here, the needle being connected with a battery by a fine wire, while the indifferent electrode was a paper-covered copper plate and was held in the palm of the hand. The spots stimulated were on the finger and back of the hand—a region where muscle twitching could best be avoided. In order to maintain a constant point of stimulation the needle was sunk slightly into the epidermis. This operation was generally painless and spots where a painful sensation was produced thereby, were discarded.

With single induction shocks, Thunberg found that, contrary to Goldscheider and Gad, a delayed sensation could be obtained on certain favored skin spots. On most spots, there appeared with this stimulus, only a single contact sensation, which became painful if the stimulus was increased. On certain spots, however, the delayed sensation appeared, but weak and unclear; while on certain others,—although these were few in number—it appeared quite clearly but was always of lesser intensity than the first sensation.

With a series of induction shocks (the apparatus for giving these being essentially identical with Goldscheider's), it was found that the appearance of the secondary sensation was again much concerned with the spot stimulated. On some spots the secondary stinging sensation was clearly obtained, on others it appeared weakly and on others not at all, the primary sensation being in all cases the same. The same individual spot differences were noticeable in the stimulations given by a brief constant current. With this method the duration of the stimulus also proved of importance. Spots, which with a brief duration gave the delayed sensation only weakly, became stronger and clearer if the length of the stimulation were increased; and the same results occurred where several brief stimulations were applied on the same spot.

In summary, three quotations will perhaps best explain the author's conclusions. "Wie es sich mit den näheren Einzelheiten auch verhalten möge, sehr wahrscheinlich ist also, dass die mechanische und thermische Reizung einen Zwischenprocess verursacht, der seinerseits die Nerven-reizung vermittelt. . . . Bei Anwendung einzelner Inductionsschläge hat die frühe Empfindung das niedrigste Minimum perceptible. Erst bei starker Reizung kommt auf gewissen Punkten eine verzögerte Sensation. Wenn man von der eben gegebenen Annahme ausgeht, dass nämlich die frühe Sensation durch directe Nervenreizung, die verzögerte durch einen durch den Reiz verursachten Zwischenprocess bedingt ist, muss diese Thatsache so gedeutet werden, dass der Inductionsschlag kräftig reizend auf den Nervenfaden selbst wirkt, aber ein sehr geringes Vermögen hat, den Zwischenprocess auszulösen. . . . Der Hauptinhalt unserer Erklärung ist also der, dass die freien Nervenenden besonders empfindlich für schwache thermische und mechanische Reize sind, aber mit langer Latenzeit reagiren. Bei directer Nervenreizung fällt die Latenzeit fort. Gleichzeitige Reizung auf diesen beiden Wegen bedingt die doppelte Schmerzsensation."

In 1903, Marillier & Philippe,[24] in a topographical cutaneous study, mention the necessity of a time interval between stimuli on account of fatigue and the persistence of previous contacts.

Haines[16] (1905) in a paper on Tactual Space Perception, states that he guards against the confusing effect of after-sensations by avoiding the successive stimulation of neighboring points.

In 1905, Urbantschitsch[37] published a paper dealing with after-sensations of various sorts but giving especial emphasis to the after-appearance of auditory and temperature stimuli. Early in this paper he cites the individual reports of his 12 subjects, from which he subsequently deduces his conclusions, without, however, attempting any tabulation of his data. In a more or less introductory way he first notes the fact that sensations incompletely or incorrectly perceived at the moment of stimulation may be corrected in the after-sensation. For example, the application on the forehead of the flat surface of an opened scissors was sensed merely as a cold wide surface but in the after-sensation was perceived as two cold strips placed at an angle.

The results of his research are included under the following headings.

(1) *Localization of Sensations.*

The after-sensations of touch and temperature were not always limited to the place of application of the stimulus but were diffused beyond, and in some cases did not appear at all at the point of stimulation but upon some neighboring spot. As an example of the first case,—a metal strip 1 cm. wide was applied to the forehead for several seconds, the cold sensation was at first limited to that point, but several seconds later it diffused itself from the center of the forehead to the eyebrows and to the bridge of the nose, there it gradually increased in intensity and then disappeared, was gone 1 minute and then reappeared near the nose. Here, the secondary sensation arose at the point where the primary ceased, but in other cases of similar spreading the secondary sensation arose at the *original* point of stimulation and followed the same course as the primary. As an example of the second case,—the center of the forehead was pricked with a needle, the pain became more intense, then suddenly disappeared and some seconds later a painful after-sensation appeared on a point above the one stimulated. In some cases the succeeding secondary sensations *each* arise in a different place. In many cases, however, both the primary and secondary sensations appear on the point of application.

(2) *Manner of Reappearance.*

Frequently the after-sensations appear first at one end of the stimulated region and from there radiate over the rest of the surface. Sometimes this radiation occurs and then the sensation retracts until it persists only on the original starting point. Or again, instead of this wave-like progression the movement may be one of oscillation, i.e. the sensation starts and then goes back.

Usually when this spreading occurred it was present with both types of stimuli but in some cases only with one. With subject 1, for example, the warm sensations were restricted to the point of contact but the cold overstepped this, while with subject 2 the overstepping occurred only with the warm sensations. In some subjects it was found that the direction of spreading always remained constant, i.e. always toward the scalp, or toward the nose. In other subjects, this constant direction depended upon the kind of stimulation, i.e. warm or cold. In subject 7 for example, the cold after-sensation always began on the upper border of the stimulated region, moved down and then up; while the reverse order was the case with warm stimuli. This phenomenon was very marked on the forearm, where with the great majority of subjects, the cold sensation always spread down and the warm upward. This observation, however, when subjected to careful examination, showed the interesting fact that by applying the stimulus—say cold—nearer and nearer to the elbow the tendency to radiate downward became less and less until a neutral zone was reached within which the area and the intensity of the sensation is limited. By passing beyond this neutral zone the direction of radiation becomes reversed, i.e. in this case it would be upward. This neutral zone was found to cover a space of from .5-1.5 cm. and was located from 9-11 cm. above the wrist joint. This reversal of direction occurred in some subjects without the intervention of this neutral zone.

(3) *Double Application Experiments.*

If, simultaneously with the application of a stimulus on a given spot a second stimulus was set down upon a neighboring spot the normal direction of spreading was usually reversed. This reversion did not occur if the second stimulus was applied on the side toward which the normal spreading inclined, i.e. if the accessory cold stimulus were placed between the original stimulus and the wrist, the spreading would continue its normal downward course. But if the accessory cold stimulus be given near the elbow, the spreading will usually be upward, and the space between the two applications will remain neutral. With the removal of the accessory stimulus, in this case, the spreading assumes its normal direction. This reversal of direction sometimes occurs if a contrary or similar stimulus be applied on the other arm or some more distant part of the body. With other subjects, however, both sensations spread in their normal directions and occupy thus only the space between their points of application; of this space the cold always occupies the greater part.*

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* It is interesting to compare these data with the results obtained by H. J. Pearce,[37] in a paper on Normal Motor Suggestibility, where it was found that the application of a second tactual stimulus increased or reversed the direction of error in localizing a skin spot previously stimulated.

### (4) *Influence of a Change of Position.*

The raising or lowering of the arm was found to be of influence. With some subjects the change of position always caused a reversal of the normal direction of spreading, while with others the spreading was always upward when the arm was raised and downward when it was lowered.

### (5) *Contrary After-Sensations.*

With the stimulation of one form of temperature sensation there frequently occurred the arousal of a temperature sensation of the opposite form, either acting simultaneously as a sort of contrast phenomenon or following after in the manner of a contrary after-sensation. Subject 7 showed a case of the contrast effect, where in the after-sensation one half the field was hot and the other half cold. And an example of the contrary after-sensation is given in subject 6, where a cold primary sensation is succeeded after an interval by a secondary warm sensation. Where this contrary after-sensation appears, the spreading, if present, follows the normal direction of the after-sensation rather than that of the original sensation.

### (6) *The Intensity of the After-Sensations.*

"In der Mehrzahl der Fälle nimmt die Temperaturempfindung nach Unterbrechung der Temperatureinwirkung auf die Haut bald rasch, bald allmählich ab, bis zu ihrem vollständigen Verschwinden, und so zeigt sich auch die Nachempfindung meistens in der früheren Stärke oder etwas abgeschwächt. Bei mehreren Versuchspersonen fand jedoch nach Entfall der betreffenden Temperatureinwirkung ein Ansteigen der Empfindung statt, oder die secundäre Nachempfindung zeigte eine grössere Intensität als die ursprüngliche Temperaturempfindung während der Einwirkung des kalten oder warmen Körpers auf die Haut. Diese Erscheinung betrifft bald das ganze Applicationsfeld, bald bestimmte Stellen innerhalb dieses."

### (7) *The Sympathetic Arousal of Earlier Stimulated Spots.*

The sympathetic arousal of earlier stimulated spots may occur with the stimulation of a neighboring spot: or if the after-sensation is in progress the second stimulation may serve to increase its intensity. This is especially true with cold sensations.

(8) *Intervals.*

The temperature after-sensations, especially cold, may have an interval of 10-15 minutes before their appearance, and they may be sympathetically called up after an even greater period. (In the individual reports earlier mentioned, however, the author often refers to an interval of "a second" or "several seconds".

(9) *After-Sensations of Touch.*

The following points are noted with regard to the after-sensations of touch. (a) They may show a change in location. After a pin prick the secondary sensation may appear not on the point of application but on a neighboring point, and successive after-sensations may likewise vary their position. Sometimes, many "stinging" sensations are said to appear so that in the after sensation the subject feels "as if a bundle of needles were set down on the skin". (b) The after-sensations may also show a change in quality from that of the original stimulus. For example, after a needle prick the after-sensation took the form of an itching, tingling sensation which extended over the whole forehead. (c) The touch after-sensations may sometimes be greater in intensity than the original stimulus.

In the first volume of his "Textbook" (1909) Titchener[34] says of the after-sensations of temperature: "A long-continued and intense cold stimulus is also followed by an after-sensation of cold. Intense stimuli, of brief duration, give a positive after-image,—the removal of a continued warm stimulus, on the other hand, leaves a sensation of coolness". After describing certain tests of thermal adaptation he says: "The after-image of cold following long-continued and intensive cold stimulation is a little paradoxical; we should rather expect an after-sensation of warmth. The cold may, in fact, be the paradoxical cold sensation, aroused in this case by the rush of warm blood to the cold-adapted regions".

## II. INTRODUCTION

During the winters and springs of 1907 and 1908 the writer undertook, at the suggestion and with the advice and assistance of Professor J. R. Angell, a study of the phenomena of cutaneous after-sensation.

### STATEMENT OF THE PROBLEM.

In beginning such a study it is necessary to recognize clearly those two types of phenomena which are variously treated as after-sensations. In the Dictionary of Philosophy and Psychology Titchener defines them briefly as follows:

"I. In the various senses brief stimulation of the peripheral organ results in (1) a primary sensation, (2) a short blank interval after the stimulus ceases and (3) a second sensation called an after-sensation.

"II. The name (after-sensation) is also given to the continuance of the sensation without pause after removal of the stimulus."

These definitions would seem perfectly applicable to the cutaneous phenomena if the statement were added, as Urbantschitsch suggests, that both types may be present in a given experience or either may appear alone. The phenomenon mentioned in II has been termed the Primary After-Sensation, or the Continuous After-Sensation of Dessoir, and this would have to be described as a sensation which *lasts after,* rather than one which *comes after* the stimulus. It is here defined as an uninterrupted continuation of the stimulus which persists for a variable time with equal or diminishing intensity. These primary after-sensations are much the more frequent in occurrence, often being the only after-effect noticeable and usually preceding the secondary sensation in cases of its appearance.

The other type of after-sensation, the one first defined by Titchener, is designated here, as elsewhere, the Secondary After-Sensation. It may make its appearance either identical in quality with the stimulus-sensation or quite different from it. This change may show as marked a difference as the contrary sensations of Preyer and Urbantschitsch, but it is more frequently associated with an intensity change, and is therefore, a change of quality rather than a change of modality,—as for example, where a tingling itching after-sensation succeeds a pure pressure stimulus-sensation. (This is of course assuming the tickle-itch complex to be due to slight stimulation of the pressure nerves as over against those authors who would provide separate nerves for each.) This secondary sensation may appear very faintly and gradually increase in intensity, or it may come into being at its maximum strength with a sudden swell or throb. It may disappear likewise in this sudden manner or it may fade away gradually. In intensity, it may be equal to that of the stimulus or it may be so faint as to be barely distinguishable.

There have been found cases where, with the removal of the stimulus or during its application, the stimulus-sensation disappeared, so that the latent period ensues immediately upon, or even previous to, the removal of the stimulus. This then, is followed by a secondary sensation, thus giving a secondary after-sensation unpreceded by a primary. Other cases are found where the secondary sensation appeared without the interruption of a clear latent interval and these cases would seem to partake of the characteristics of both the primary and secondary sensations. An example will perhaps best describe such a case. Stimulus areal cold: after removal of the cylinder the stimulus persists for a little while with rapidly diminishing intensity and is succeeded by a period of cool tingling over the whole area, so faint as to be scarcely discernible. Then there recurs a sudden pulse of cold, identical in quality with, and almost as intense as, the stimulus-sensation. Here is an instance of an after-sensation uninterrupted from the removal of the stimulus to the moment of its final disappearance, and as such it should be classed as primary. But quite as important to the definition of the primary sensation is its "diminishing intensity" and such a recurrence of vivid cold would therefore exclude it from this class. This fact would seem to outweigh the consideration of the lack of an absolute clear latent interval, so that such cases will be ranked in the tables as secondary sensations. We should therefore have to amplify our definition of the secondary after-sensations to include those which make their appearance after a clear latent interval or after a period of diminished intensity.

The short blank period preceding the secondary sensations has been termed the latent interval. Its relations to the primary sensations have just been described. It is here defined as a clear sensationless pause before the secondary sensation and is not intended to include those periods of diminished intensity just mentioned.

### NON-ILLUSORY CHARACTER OF AFTER-SENSATIONS.

The criticism has sometimes been urged that these secondary after-sensations are, in reality, nothing more than the perception of those common muscular and organic feelings which ordinarily pass unnoticed, but which can be called out by concentrating the attention on a given portion of the skin. In order to determine whether the after-phenomena involve anything beyond such a subjective concentration, the re-agents of the following experiments were given a series of test experiments in which they were told to concentrate all attention possible on an indicated skin area and to record the resulting sensations. This test was given at the beginning of the experimentation and again, on the chance that the practice thus obtained in cutaneous introspection might have some effect, later on in the series. The results in the two cases were essentially similar and are summarized below. The subjects were asked to compare these results with those of cases where after-sensations were clearly obtained.

I. Gets no sensation. With the eyes closed gets only vague visual images of the region. In no way similar to after-sensation phenomena.

II. No sensation at all. Very different from after-sensation.

III. No sensation at all. Very different from after-sensation.

IV. Feels unlocalized tendinous strain and pulsation. None of the definiteness of after-sensation.

V. Feeling of slight superficial strain; wholly different from after-sensation.

VI. Feels a vague warmness over the area. Much more vague and diffuse than the after-sensation of warmth.

It would likewise seem probable that if these phenomena were of purely subjective nature there would be some individual type of response,—that is to say, with one subject all the secondary sensations might make their appearance gradually or might always come in waves, while with another the returns would tend to be abrupt. From the qualitative tables (vide infra) it will be shown however, that such is not the case; that the after-sensations tend to show differences characteristic of the various stimuli rather than differences characteristic of individual subjects. (Cf. Individual Tables.)

### INFLUENCE OF ATTENTION.

It is likewise open to contention that these phenomena may be explained simply in terms of attention. The primary after-sensation followed by a latent period, then the secondary sensation followed in turn perhaps by a succession of after-sensations, each separated by a sensationless pause are strikingly comparable to the phenomena described by Sergi, Grandis, Kiesow, and others and attributed by them to the oscillations of attention. While it is not to be denied that in the investigation of cutaneous after-sensations the influence of attention was found very considerable, the phenomena as a whole cannot be so summarily disposed of. In the first place, the methods used by the investigators mentioned were either (1) by means of a continuous stimulation, in which the effects of partial adaptation must surely have been effective as well as the attention factor, or (2) by the use of minimal stimuli—while all the stimulations given in our experiments were well above the threshold. Although, as was just stated, the stimuli employed here were always of sufficient intensity to be clearly and easily perceived, that does not prohibit the possibility of many of the after-sensations making their appearance with considerably lessened strength. In such cases, it is undoubtedly true that the apperception of these at their moment of entrance probably depends largely on the direction of the attention at that instant, and, it is this fact that makes any exact measurement of the latent period impossible. It is very probable that there may have been cases where the secondary sensation, being of this minimal intensity, and being likewise brief, may, by reason of the oscillations of attention, have been completely overlooked; so that many, or possibly all, of the cases recorded as giving "primary after-sensations alone" may be of this nature. Thunberg states that he finds it more difficult to understand the cases where these secondary sensations do not appear than those where they do, and such an explanation might perhaps serve. The percentage of cases, however, in which the fading primary sensation, the clear sensationless interval, and the sudden recurrence of the secondary sensation stand out clearly and intensely, together with the subjects' introspective certainty of the process, makes any explanation of the phenomena as dependent upon purely central factors, of the nature of imagination, quite impossible.

In order, however, accurately to test the matter a limited number of experiments was given to subjects II, V, and VI, as follows: The stimulus was given, then, as the primary sensation was dying away, the subject was instructed to begin reading aloud from a relatively unfamiliar book and to indicate any recurrence of sensation. It was found that with subject V, out of ten stimulations of areal pressure given under these conditions, three recurrences appeared with such vigor as to break into the field of attention. With subject II, the same occurred twice with contact cold, and twice also with subject VI, where the stimulus was punctiform pain.

There were also many cases throughout the experiments where a subject, thinking the secondary sensation had exhausted its recurrences, or was not to appear at all, had begun to record his introspection when the after-sensation appeared with such vividness as instantly to call back the attention to the stimulated area.

# III. EXPERIMENTATION

No attempt was made to make this investigation an exactly quantitative one, for the reasons given below, but rather a comparison was sought of the relative strength and frequency of the after-sensation in various fields, and of the relative preponderance of primary or secondary after-sensations.

## METHOD OF INVESTIGATION.

Six subjects, three men and three women, were used for these experiments, all of whom were graduate students in psychology and competent introspectionists.

The experiments were carried on during a period of ten months, each sitting not exceeding half an hour in duration in order to avoid fatigue. The number of stimulations given at a sitting varied with the kind of stimuli in use and with the individual subject, as it was essential that the after-effect of previous stimulation should be completely dissipated before the next was given, and the relative persistence of the same varied with the two factors just mentioned. More than ten experiments were never given in a series and at times the number of tests was as low as three. During each sitting the subject signified the progress of the experiment by a series of prearranged words or movements—the record of which was taken down by the operator with the aid of a split second stop-watch. After each test, the subject gave a full introspective report of the entire process which was transcribed verbatim. The majority of the tests were given on the hands and forearms. The arm rested comfortably on a cushioned table and the temperature of the room was kept as nearly as possible normal.

Eleven forms of stimulation were used,—Areal pressure (contact), punctiform pressure (contact), radiant heat (no contact), areal heat (contact), punctiform heat (contact), electrically stimulated punctiform heat, radiant cold (no contact), areal cold (contact), punctiform cold (contact), electrically stimulated punctiform cold, punctiform pain (pricking).

The technique employed for each form of stimulation was as follows:

I. *Areal Pressure.* Rounded cork points 1/8 and 1/4 in. in diameter, thermally neutral, applied carefully by hand, with a varying velocity and an intensity ranging from approximately 20-200 gr. for intervals of time varying from 1-10″.

II. *Punctiform Pressure.* Rounded wooden points 1/32 in. in diameter, and von Frey's "pressure hairs". These were applied, in the usual way, upon pressure spots which had been located and marked several days previous.

III. *Radiant Heat.* Brass "temperature cylinders," 6 cm. long and ½ cm. in diameter, were heated 3-5′ in a Bunsen burner, and brought as close as possible to the skin without touching it. Metal discs warmed to "red heat" were also used in the same manner.

IV. *Areal Heat.* Temperature cylinders of III, heated until the metal is distinctly but not unpleasantly warm to the touch, and applied to the skin with as little pressure as possible. These were removed as soon as a clear sensation of warmth was felt.

V. *Punctiform Heat.* Brass temperature cylinders, 1 mm. in diameter, heated and applied as in IV, to "hot spots" located and marked several days previous. The cylinders were removed when a clear sensation of warmth was felt.

VI. *"Electric Heat."* "Hot spots" were located by temperature cylinders, these were marked and after a 24-hr. interval were stimulated by means of the Du Bois-Raymond induction coil, a copper wire, 1 mm. in diameter being used for a stimulation-point. The shock was graduated to avoid undue muscular twitching.

VII. *Radiant Cold.* Temperature cylinders, cooled for 10-30′ in ice and salt were approached close to the skin. A metal tube 3 in. in diameter, having a base of sheet rubber was filled with finely chopped ice and salt and used in the same way. These were removed as soon as the coldness was sensed.

VIII. *Areal Cold.* Temperature cylinders and a metal disc 1 in. in diameter were cooled as in VII. These were carefully wiped dry and applied to the skin with as little pressure as possible. They were removed as soon as the cold was clearly felt.

IX. *Punctiform Cold.* Same method used as with punctiform heat. Cylinders cooled as in VII.

X. *"Electric Cold."* Same method used as in VI.

XI. *Punctiform Pain.* Pain spots were located and marked, a 24-hr. interval was allowed and then they were stimulated by sharpened hog bristles and fine needle points.

Under each of three type headings, three sets of tables are given which will attempt to state the results obtained in (A) Numerical, (B) Quantitative, and (C) Qualitative form.

The Numerical table (A) shows in every case, (1) the number of stimulations given, (2) the number of primary, and (3) the number of secondary after-sensations obtained. (4) Shows the number of cases where the primary sensations appeared alone, i.e. unsucceeded by a secondary, (5) the cases where the primary sensation ceased with, or during, the stimulus so that the secondary sensation made its appearance after a latent interval unpreceded by a primary sensation. (6) Shows the number of latent intervals, i.e. clear sensationless pauses which precede the secondary sensation. (7) Indicates the number of times the secondary sensation recurred more than once. It is not intended to indicate the actual number of recurrences. (8) Records the number of times when after-sensations failed to appear, i.e. where the sensation disappeared with or during the stimulus and did not recur. (9) Shows the percentage of primary, and (10) of secondary after-sensations obtained from the total number of stimulations.

Table B, is intended to show in a general way the quantitative measurements of the primary and secondary sensations and of the latent interval. As was earlier stated, it was found impracticable, if not impossible, to give any exact measurements as to the duration of these phenomena. The primary after-sensation was found the most easy to gauge introspectively, and the moment of cessation of the secondary could be indicated without much difficulty. The moment of appearance of the secondary sensation, however, and in consequence the moment of departure of the latent interval, was in many cases tremendously difficult of analysis, because this sensation appeared so gradually and was, at that moment, so easily to be confused with the general sensations present over the whole area. It has seemed best, therefore, to include in this table only those cases where the secondary sensation "appeared suddenly", "welled up", or "blazed out" in its full intensity. The stop-watch method is admittedly inexact, especially in comparison with the apparatus used by Goldscheider and Thunberg, but in view of the fact that (1) the measurable cases comprised less than a third of the total number of secondary sensations obtained; (2) that any slight noise, such as that of a kymograph, was found to be very distracting, and (3) most especially in consideration of the fact that our object was to obtain a comparative record of the *relative* persistence and intensity of the different types, rather than exact figures on any one, and, since this method was identical in all cases, it amply served that purpose and any further elaboration seemed unnecessary.

It has seemed in fact that this is not a field where quantitative measurement is at present possible. Considering first the stimulus—its objective strength may be carefully equated in each experiment but the relative sensitivity of different areas, even of the same general region, would cause its subjective perception to vary in a manner incalculable in physical units. Or if, as has been done, the same spot is used in every case, the well known rapid fatigue of the cutaneous sense organs would have the same effect before enough tests were taken to give any quantitative certainty. The duration of the stimulus, likewise, will vary subjectively, for the difference in the apperception-time of the different skin areas would serve in some cases to alter an objectively equal time of stimulation. In the matter of the primary after-sensation, the moment of beginning is arbitrarily fixed by the removal of the stimulus, but in those cases where the sensation fades out gradually its actual intensity at the moment of passing below the threshold does not always coincide with the intensity of the secondary sensation at the moment of its emergence, because, we have in one case a series descending to a conscious limen and in the other case one ascending to the same limen from below; and the threshold in the first case would be lower. The moment of ending of the latent interval and in consequence the moment of appearance of the secondary sensation is likewise questionable. For the intensity with which the secondary sensation returns is widely variable, so that the time of apperception of an after-sensation would follow the same laws as the apperception of a sensation, i.e. would vary with the intensity of the same,—at least throughout the range with which we are dealing here.

The figures given in the quantitative table are all subject to these objections and are therefore to be regarded as general indications rather than exact measurements of the phenomena in question. It has seemed best to group the durations of the after-sensations under the heading "very brief", i.e. under 2″, "brief", i e. 2-15″, "moderate", 15-60″, and "long" over 60″; and to tabulate the latent periods as "short", i.e. under 1″, "moderate" 1-30″, and "long" over 30″.

Table C deals with the qualitative nature of the after-phenomena. (1) Indicates simply the quality of the secondary sensation. (2) Records the changes in quality which may occur. (3) Shows the intensity of the after-sensation and, (4) its localization or change in location, (5) Indicates the manner of appearance of the secondary sensation and, (6) the manner of disappearance of, (a) the primary and (b) the secondary after-sensation.

In the accompanying inserts there is given the report of each individual subject obtained by each form of stimulation used. These, like the combined tables, are grouped under the headings Numerical, Quantitative and Qualitative.

Supplementary to our main experiments a limited number of others were made as follows: (1) Experiments in which corneal pain was the stimulus and the author the sole reagent. (2) Experiments in which a linear pressure stimulus was contrasted with that of a pressing point moving over a space equal to that of the linear extent (3 subjects served here). (3) Experiments in which subjects were tested with the stimuli of heat, cold, and pressure on skin areas anæsthetised by ethyl chloride. (4) Experiments in which an attempt was made to reproduce Goldscheider's conditions (Cf. Historical Statement) of electrical stimulation (2 subjects were here used). Descriptions of the technique employed in these tests are given on pp. 65, 72-73, 74-78, and 84-86 respectively.

## DIGEST OF COMBINED RESULTS.

By reducing the individual data (cf. Individual Tables) to general percentages we obtain the tables which follow:

### *A. Combined Numerical Tables.*

TABLE I.

PERCENTAGE OF AFTER-SENSATIONS. (PRIMARY AND SECONDARY.)

| | |
|---|---|
| Areal Cold | 94.8% |
| Punctiform Pain | 93.5% |
| Areal Heat | 89.3% |
| Areal Pressure | 88.4% |
| Punctiform Cold | 84.7% |
| Punctiform Pressure | 79.3% |
| Punctiform Heat | 79.3% |
| Radiant Heat | 74.5% |
| Radiant Cold | 67.9% |
| Electric Cold | 59.3% |
| Electric Heat | 58.3% |

Such a table seems to indicate—(1) that after-sensations result from the given stimuli in the following order of frequency,—areal cold, punctiform pain, areal heat, areal pressure, punctiform cold, punctiform heat and pressure, radiant heat, radiant cold, electric cold, and electric heat; (2) that when punctiform and areal forms of the same stimulus are given, the areal is more productive of after-sensations; (3) that with temperature stimuli the contact method is more reliable than the radiate or electric; (4) that the order is cold, heat, pressure for both punctiform and areal stimulations and that the percentage difference between cold and heat is greater than that between heat and pressure in both cases: (5) that radiant heat is the only case where a heat stimulus is more effective than a cold of the same type.

TABLE II.

PERCENTAGE OF PRIMARY AFTER-SENSATIONS.

| | |
|---|---|
| Areal Cold | 92.7% |
| Areal Heat | 86 % |
| Punctiform Pain | 85.2% |
| Areal Pressure | 82.8% |
| Punctiform Cold | 80.6% |
| Radiant Heat | 76.6% |
| Punctiform Heat | 74.1% |
| Punctiform Pressure | 73.6% |
| Radiant Cold | 67.9% |
| Electric Cold | 59.3% |
| Electric Heat | 58.3% |

(1) For primary after-sensations the order of precedence is,—areal cold, areal heat, punctiform pain, areal pressure, punctiform cold, radiant heat, punctiform heat, punctiform pressure, radiant cold, electric cold, electric heat. This arrangement is identical with that of the first table with the exception of radiant heat, which is here given a higher percentage than punctiform heat and pressure. (2) The order cold, heat, pressure, with the greater interval lying between cold and heat, holds true for both areal and punctiform stimulations. (3) Areal forms are likewise more suited than punctiform to the production of primary after-sensations but (4) punctiform heat by giving a lesser percentage than radiant is an exception to the rule that contact stimuli are more favorable than radiant or electric, but the difference is very slight. (5) Radiant heat is the only case where a heat stimulus is more effective than a cold of the same type, but the greater radiate energy of this form of stimulus may account for this discrepancy. (6) As to the actual figures it will be seen that the percentages of primary after-sensations of the different stimuli correspond very closely to those of Table I. The greatest divergence is in the case of punctiform pain and punctiform pressure.

This table is to be compared with one showing the percentages of Secondary After-Sensations.

TABLE III.

PERCENTAGE OF SECONDARY AFTER-SENSATIONS.

| | |
|---|---|
| Punctiform Pain | 73.8% |
| Areal Cold | 71.9% |
| Radiant Cold | 70.8% |

| | |
|---|---|
| Areal Heat | 65.3% |
| Punctiform Cold | 63.9% |
| Punctiform Heat | 60.3% |
| Areal Pressure | 54.2% |
| Punctiform Pressure | 47.2% |
| Electric Cold | 40.7% |
| Electric Heat | 37.5% |
| Radiant Heat | 34 % |

(1) In this table the order stands—punctiform pain, areal cold, radiant cold, areal heat, punctiform cold, punctiform heat, areal pressure, punctiform pressure, electric cold, electric heat, radiant heat. This differs from the first two in giving punctiform pain a greater percentage than areal cold and in making both forms of contact temperature stimuli more effective than areal pressure. (2) Areal forms are in every case more suitable than punctiform, although the difference between them is less than with the primary. (3) Cold stimuli are more effective than similar heat stimuli, and (4) the order cold, heat, pressure is true for both punctiform and areal stimulations although the greater interval here lies between heat and pressure. (5) The figures in this table show a marked lessening from those of the primary after-sensations. Numerically they are on an average about a third less,—that is to say, for every case where a secondary after-sensation was obtained there were approximately two instances of primary after-sensations. A table of the relative preponderance of primary over secondary is given below in descending order.

TABLE IV.

THE RELATIVE PREPONDERANCE OF PRIMARY OVER SECONDARY AFTER-SENSATIONS.

| | |
|---|---|
| Radiant Heat | 42.6% |
| Areal Pressure | 28.6% |
| Punctiform Pressure | 26.4% |
| Radiant Cold | 22.6% |
| Areal Cold | 21.9% |
| Areal Heat | 21.4% |
| Electric Heat | 20.8% |
| Electric Cold | 18.6% |
| Punctiform Cold | 16.7% |
| Punctiform Heat | 13.8% |
| Punctiform Pain | 11.4% |

This table indicates that—(1) areal stimulations in every case show a greater preponderance of primary over secondary sensations than do the punctiform and electric stimulations of the same type, and that (2) radiant heat shows this preponderance much more strongly than any of the other forms.

The presence of a clear latent interval preceding the appearance of the returning sensation was, it will be remembered, only present in certain cases, its place being taken in the remainder by a considerable diminishing of the primary after-sensation.

TABLE V.

PERCENTAGE OF LATENT INTERVALS.

| | |
|---|---|
| Areal Pressure | 38.3% |
| Punctiform Pressure | 30.2% |
| Punctiform Pain | 29.5% |
| Punctiform Heat | 27.6% |
| Punctiform Cold | 25 % |
| Areal Heat | 16 % |
| Areal Cold | 11.5% |
| Radiant Heat | 8.5% |
| Electric Heat | 8.3% |
| Electric Cold | 7.4% |
| Radiant Cold | 0 % |

This table shows rather a reversal of previous conditions in that; (1) pressure and pain stimuli seem most favorable for this type of response; (2) heat, in all its forms, is more effective than cold and that; (3) with the temperature stimuli, although such is not the case with pressure, punctiform stimuli give better results than areal.

TABLE VI.

PERCENTAGE OF SECONDARY AFTER-SENSATIONS ALONE.

| | |
|---|---|
| Punctiform Pain | 8.2% |
| Punctiform Heat | 5.2% |
| Areal Pressure | 5.2% |
| Punctiform Cold | 4.2% |
| Areal Heat | 2.7% |
| Areal Cold | 2.1% |
| Punctiform Pressure | 1.9% |
| Radiant Heat | 0 % |
| Electric Heat | 0 % |
| Radiant Cold | 0 % |
| Electric Cold | 0 % |

(1) The order of preponderance in this table is not unlike that in the preceding, punctiform pain being here given first place and the pressure stimuli, especially punctiform pressure, being ranked lower down. As in table V (2) heat appears more effective than cold and (3) again with the exception of pressure, the punctiform stimuli are more favorable than the areal. (4) Neither radiant nor electric stimuli produced a secondary sensation unaccompanied by a primary. (Table V shows the percentage of latent intervals obtained by these stimuli to be very small.)

TABLE VII.

PERCENTAGE OF RECURRENT SECONDARY AFTER-SENSATIONS.

| | |
|---|---|
| Punctiform Cold | 26.4% |
| Punctiform Heat | 13.8% |
| Punctiform Pain | 13.1% |
| Punctiform Pressure | 11.3% |
| Radiant Heat | 8.5% |
| Electric Heat | 8.3% |
| Areal Pressure | 7.5% |
| Radiant Cold | 7.5% |
| Electric Cold | 7.4% |
| Areal Cold | 7.3% |
| Areal Heat | 4 % |

From this it is to be seen: (1) that punctiform stimuli give the best results—cold being especially favorable—although (2) the other forms of contact temperature stimuli, i.e. areal, were found less effective than radiate and electric,—areal heat giving a strikingly low percentage.

The last table in this series gives the percentages of primary after-sensations unaccompanied by secondary; it is to be compared with table II.

TABLE VIII.

PERCENTAGE OF PRIMARY AFTER-SENSATIONS ALONE.

| | |
|---|---|
| Radiant Heat | 38.3% |
| Areal Pressure | 33.4% |
| Punctiform Pressure | 28.3% |
| Areal Heat | 22.7% |
| Areal Cold | 21.8% |
| Electric Heat | 20.8% |
| Punctiform Cold | 20.8% |
| Punctiform Pain | 19.7% |

| | |
|---|---|
| Punctiform Heat | 19 % |
| Radiant Cold | 18.9% |
| Electric Cold | 18.6% |

(1) This follows the general rule of table I in having areal stimuli more effective than punctiform but otherwise differs from it. (2) Heat and pressure, except for the punctiform types, are more suitable than cold,—radiant heat being preëminently favorable. (3) Punctiform pain gives a relatively low percentage.

### *B. Combined Quantitative Tables.*

The following tables contain percentages of the quantitative measurements. These are submitted with some hesitation, because, for the reasons earlier given, the figures represent but a small part of the total results (pp. 37-39).

TABLE IX.

PERCENTAGE OF THE DURATIONS OF PRIMARY AFTER-SENSATIONS.

| | VERY BRIEF (-2") | BRIEF (2-15") | MODERATE (15-60") | LONG (60"+) |
|---|---|---|---|---|
| Areal Pressure | 13.7% | 27.3% | 45.4% | 13.7% |
| Punctiform Pressure | 17.2% | 24.1% | 31 % | 27.6% |
| Radiant Heat | 4.3% | 30.4% | 43.5% | 21.7% |
| Areal Heat | 3.7% | 11.1% | 33.3% | 51.8% |
| Punctiform Heat | 4.2% | 20.8% | 37.5% | 37.5% |
| Electric Heat | 0 % | 42.8% | 0 % | 57.1% |
| Radiant Cold | 0 % | 40 % | 40 % | 20 % |
| Areal Cold | 6.2% | 8.3% | 33.3% | 52.1% |
| Punctiform Cold | 8.1% | 10.8% | 40.5% | 40.5% |
| Electric Cold | 0 % | 33.3% | 41.7% | 25 % |
| Punctiform Pain | 0 % | 19.4% | 30.5% | 50 % |

The question at once arises whether those stimuli most suited to the production of primary after-sensations give also the greatest percentage of "long" or at least "moderate" durations; and from a comparison of this table with Table II this is shown, in general, to be the case. Areal pressure, it is true, is here given only 13.8% of "long" durations but the percentage of "moderate" is very large. This is true likewise for radiant heat. Electric heat is also ranked above its place in the numerical table but in this case there are no sensations of "moderate" length so 57% represents all the after-sensations which endured beyond 15".

## TABLE X.

### PERCENTAGE OF THE DURATIONS OF LATENT INTERVALS.

| | SHORT (–1″) | MODERATE (1–30″) | LONG (30″+) |
|---|---|---|---|
| Areal Pressure | 54 % | 29.7% | 16.2% |
| Punctiform Pressure | 20 % | 40 % | 40 % |
| Radiant Heat | 0 % | 0 % | 100 % |
| Areal Heat | 66.6% | 33.3% | 0 % |
| Punctiform Heat | 50 % | 0 % | 50 % |
| Electric Heat | 0 % | 0 % | 100 % |
| Radiant Cold | 0 % | 0 % | 0 % |
| Areal Cold | 25 % | 25 % | 50 % |
| Punctiform Cold | 20 % | 40 % | 40 % |
| Electric Cold | 0 % | 0 % | 0 % |
| Punctiform Pain | 33.3% | 8.3% | 58.3% |

From such a table the most evident conclusions to be drawn are,—(1) that areal heat stimuli are most apt to give brief latent intervals, while (2) cold, on the contrary, more generally produce long intervals; (3) that secondary sensations of pressure, especially areal pressure, usually make their appearance after short or moderate intervals, and (4) after-sensations of punctiform pain are generally preceded by long intervals but more often by short than by moderate. (5) Radiant and electric heat seemingly give a high percentage of long durations but it is to be remembered there were very few latent intervals reported with either of these stimuli. (6) The latent intervals do not show any striking difference in duration between punctiform and areal forms of the same stimulus except in the case of heat where an areal stimulus gave 0% long intervals and a punctiform 50%.

## TABLE XI.

### PERCENTAGE OF THE DURATIONS OF SECONDARY AFTER-SENSATIONS.

| | VERY BRIEF (–2″) | BRIEF (2–15″) | MODERATE (15–60″) | LONG (60″+) |
|---|---|---|---|---|
| Areal Pressure | 10.4% | 16.7% | 41.7% | 31.2% |
| Punctiform Pressure | 20 % | 20 % | 20 % | 0 % |
| Radiant Heat | 0 % | 0 % | 100 % | 0 % |
| Areal Heat | 0 % | 18.2% | 36.4% | 45.4% |
| Punctiform Heat | 0 % | 0 % | 63.6% | 36.4% |
| Electric Heat | 0 % | 0 % | 0 % | 0 % |
| Radiant Cold | 0 % | 0 % | 0 % | 0 % |
| Areal Cold | 0 % | 0 % | 26.9% | 73.1% |
| Punctiform Cold | 0 % | 0 % | 31.2% | 68.7% |
| Electric Cold | 0 % | 16.7% | 50.1% | 33.4% |
| Punctiform Pain | 0 % | 34.8% | 34.8% | 30.4% |

From such a table it is seen that: (1) Pressure is the only stimulus which calls out a form of almost instantaneous after-sensation, i.e. "very brief"; (2) Pain stimuli give almost equal proportions of brief, moderate and long after-sensations; (3) Cold gives by far the greatest proportion of long after-sensations and none at all under 15″, and as regards this duration it is a matter of indifference whether the areal or punctiform method be used; and (4) with punctiform heat stimuli all the after-sensations are long or moderate and with areal heat 80% of them. Comparing this table with the numerical table of secondary after-sensations we see very little similarity between the stimuli most frequently producing after-sensations and those giving the longest durations. It may be said, however, that cold ranks above heat in order of their duration and both above pressure. Comparing this table with the table of latent intervals it can be seen: (1) that the pressure stimuli which give the greatest proportion of brief after-sensations give also the least proportion of long latent intervals; (2) that one third of the latent intervals from pain stimuli are short as are also one third of its after-sensations; (3) that the combined forms of contact cold give a greater proportion of long intervals than do the combined heat contact stimuli—a comparison which agrees with the proportion of long after-sensations of these two; and (4) that areal heat gives a greater proportion of both short latent intervals and brief after-sensations than does punctiform heat.

### C. *Combined Qualitative Results.*

These results are by far the most difficult to interpret involving as they do peculiarities both of individual expression and response. Some subjects, for example, might call a sensation "prickling" which another would designate "tingling", while the variations in skin thickness, etc., of different subjects may cause an actual difference in sensation with the more delicate stimuli.

TABLE XII.

PERCENTAGE OF THE QUALITIES OF SECONDARY AFTER-SENSATIONS.

AREAL PRESSURE.

Dull pressure 44.6%; prickly 5.9%; throbbing 5.9%; tingling 13.1%; tickling 11.9%; deep tendinous feeling 1.2%; contact + pressure 1.2%;

strain 1.2%; soft elastic feeling 2.4%; stinging 1.8%; sharpness 3.6%; callous spot feeling 1.2%; cold .6%; cool .6%; cool tickling 2.4%; warmth 1.8%.

PUNCTIFORM PRESSURE.

Pressure 44%; cold and pressure 8%; prickinb 12%; pain prickle 8%; sharpness 8%; painful itching 8%; pressure and soreness 4%; throbbing 4%; pressure and pain 4%.

RADIANT HEAT.

Warm 25%; hot 18.7%; neutral indescribable sensation 12.5%; indefinite tingling 6.2%; slight warmth and smarting 12.5%; peculiar pain and throbbing 12.5%; cool 12.5%.

AREAL HEAT.

Pure warmth 34.6%; smarting 16.3%; tingle 6.1%; prickling 4.1%; cool menthol feeling 6.1%; hot, burning 8.2%; heat and touch 8.2%; pressure and smarting warmth 10.2%; cold 4%; cool 2%.

PUNCTIFORM HEAT.

Clear distinct warmth 28.5%; faint warmth 17.1%; almost a burn 14.3%; painfully warm, burning 11.5%; burning feeling of menthol 2.9%; warm pressure 11.4%; warm prickling 5.7%; large diffuse pain 2.9%; tingling 2.9%; prickling 2.9%.

ELECTRIC HEAT.

Warm 33.3%; hot 11.1%; sort of burning sensation 33.3%; smarting, biting 11.1%; cold 11.1%.

RADIANT COLD.

Clear cold 16.7%; cool 70.8%; rheumatic pain 8.3%; warm 4.2%.

AREAL COLD.

Vivid cold identical with stimulus 52.9%; cool subcutaneous vapor 1.5%; cool 4.4%; burning cold 4.4%; cold and pressure 7.3%; cold and wet 5.8%; cold and contact 10.3%; pressure 1.5%; tingle and throb with pressure 1.5%; tickle 4.4%; wet and heavy 1.5%; moist, no pressure 1.5%; tingling 1.5%; warm 1.5%.

PUNCTIFORM COLD.

Pure cold 60.9%; burning cold 2.2%; cold and pressure 2.2%; cold and touch 6.5%; cold and wet 6.5%; cold tingle 2.2%; cool wave 2.2%; cool itching pain 2.2%; faint rheumatic pain 2.2%; pricking 2.2%; stinging 4.3%; tingle 6.5%.

ELECTRIC COLD.

Cold 81.8%; cool tingle 9.1%; pricking pain 9.1%.

PUNCTIFORM PAIN.

Pure, clear pain 51.1%; somewhat painful 2.2%; pain and pressure 8.9%; sharp contact 4.4%; sharp beating 4.4%; perhaps painful pressure 4.4%; pricking and throbbing 8.9%; general ache 11.1%; pressure with tingle 2.2%; pressure with ache 2.2%.

Such a table clearly indicates, that every form of stimulus used gives a much greater proportion of secondary after-sensations *qualitatively similar* to the stimulus than differing from it. It can be seen too, that this is more evident with punctiform than with areal forms of the same stimulus, punctiform heat being especially noticeable. The electric forms of stimuli as well as radiant cold seem to be especially favorable to this identical reproduction. Pressure stimuli produce a qualitatively different after-sensation more frequently than do temperature.

TABLE XIII.

PERCENTAGE OF CHANGES IN THE QUALITY OF SECONDARY AFTER-SENSATIONS.

Areal Pressure.

Pressure ends in tickling 2.4%; cutaneous feeling changes to tendinous strain .6%; pressure changes to tingling and beating .6%; pressure changes to indescribable quality 1.2%; delicate pressure changes to pressure + sting .6%; pressure changes to warmth 1.2%; pressure ends in tickling .6%; pressure changes to cool .6%; alternate pressure and contact .6%; dull pressure, to cool, to pressure .6%.

Punctiform Pressure.

Pressure changes to sharpness 4%; pressure changes to pain 4%; cold and pressure, cold goes leaving pressure 4%; cold and pressure, pressure goes then a return like the original 4%.

Radiant Heat.

Returned cold 12.5%.

Areal Heat.

First return pressure then warm then cold 2%; cold returns 8.2%; cool returns 4.1%; pressure then warm then cold 2%; warm changes to throbbing 2%; pressure and heat then only heat 2%; returns cold then warm then cool 2%; neutral primary sensation is burning in secondary 2%.

Punctiform Heat.

Prickly feeling to menthol feeling 2.9%; menthol feeling to warmth 2.9%; pain to warm pricking 2.9%.

Electric Heat.

Cold returns 11.1%.

Radiant Cold.

Returns warm 4.2%.

Areal Cold.

Cold and touch, touch goes cold remains 1.5%; first return cold and contact, recurrences are pure cold 1.5%; stimulus pressure and cold only cold in after-sensation 5.8%; first recall pressure, second cold, third pressure 1.5%; returns warm 1.5%.

Punctiform Cold.

Cold tingle changes to pure cold 2.2%.

Electric Cold.

Returns warm, then cold then warm 9%; cold, then a pulse of pain 9%.

Punctiform Pain.

Pain and pressure changes to pressure alone then pain alone 2.2%; pain to contact 2.2%; pain to pressure 2.2%; sharp pressure to sharp pain 2.2%; pain settles into ache 4.4%; pain and pressure, pain fluctuates while pressure stays constant 2.2%; ache, with periods of prickling 2.2%; throbbing and pressure alternate 2.2%; two pressure returns then pressure + tingle 2.2%; first return pain, second an ache 2.2%; primary after-sensation is coldish, secondary only pain 2.2%; stimulus only touch stinging pain in the after-sensation 2.2%; touch and pain alternate 6.7% return pressure and pain 2.2%; primary is pain and pressure, secondary only pain 2.2%; first return sharp pain, second, pressure 2.2%.

It is evident that secondary sensations *may make their appearance* changed in quality, i. e. different from the primary, or the change may come in some one of the succeeding recurrences or again, they may change qualitatively during their continuance. The so-called "contrary after-sensations", i. e. heat to cold and vice versa, never made their appearance in this third manner, although there were cases where pressure changed gradually to warm and to cold, and where heat changed into contact, and cold into pain. The relative proportion of quality changes which took place in this manner, i. e. by a gradual shading of one sensation into another, stand in the following order: punctiform pressure 12%, punctiform heat 11.6%, punctiform pain 11%, areal pressure 8.4%, punctiform cold 2.2%, areal heat 2%, and areal cold 1.5%. From which it appears, that punctiform stimuli are more suitable than areal and that the order is pressure, heat, cold for both areal and punctiform stimuli. Electric and radiate stimuli show no changes of this type. This table also shows that heat gives a greater percentage of contrary after-sensations than cold —39.8% as against 14.7%. No contrary after-sensations were obtained with either punctiform heat or punctiform cold.

## TABLE XIV.

PERCENTAGE OF THE INTENSITIES OF SECONDARY AFTER-SENSATIONS

AREAL PRESSURE.

Faint 42.3%; moderate 16.1%; hard and vivid 29.2%; stronger than stimulus 12.5%.

PUNCTIFORM PRESSURE.

Mild 24%; distinct 12%; strong, intense 44%; equal to stimulus 20%.

RADIANT HEAT.

Mild 50%; not intense 31.2%; intense and definite 18.7%.

AREAL HEAT.

Faint, mild 37%; moderately intense 22.4%; strong, intense 18.4%; very distinct 18.4%; stronger than stimulus 4%.

PUNCTIFORM HEAT.

Faint, mild 34.3%; moderately strong 25.7%; strong 25.7%; very intense 5.7%; painfully warm 5.7%; strong as stimulus 2.9%.

ELECTRIC HEAT.

Mild 11.1%; quite strong 33.3%; moderate 22.2%; intense 11.1%; very intense 22.2%.

RADIANT COLD.

Faint 62.5%; moderate 25%; definite 4.2%; strong 8.3%.

AREAL COLD.

Mild 7.3%; less distinct 2.9%; moderate 4.4%; intense 58.8%; strong as stimulus 7.3%; very intense 11.8%; stronger than stimulus 7.3%.

PUNCTIFORM COLD.

Faint, mild 28.3%; moderate 2.2%; strong, distinct 56.5%; strong as stimulus 4.3%; *very* intense 8.7%.

ELECTRIC COLD.

Mild 18.2%; moderate 27.3%; very clear 45.4%; intense 9%.

PUNCTIFORM PAIN.

Faint 31.1%; strong 33.3%; steady 4.4%; less intense, moderate 8.8%; strong as stimulus 6.7%; intense 15.6%.

Adopting a purely arbitrary method of gradation, i. e. counting the response "faint" as 1, "moderate" as 2 etc., and with the assistance of the introspective comparisons of our subjects we find the after-sensations taking the following order according to their respective intensities,—areal cold, punctiform cold, punctiform pressure, punctiform pain, areal pressure, areal heat, electric heat, punctiform heat, electric cold, radiate heat and radiate cold. It therefore appears that areal and punctiform cold after-sensations are more intense than warm, and that areal stimuli give stronger after-sensations than punctiform except in the case of pressure.

## TABLE XV.

### PERCENTAGE OF THE LOCALIZATIONS OF SECONDARY AFTER-SENSATIONS.

AREAL PRESSURE.

Diffuse or spread 50.6%; massive and unlocalized 3.6%; sharply localized 31.1%; limited to a definite area 3.6%; localized as ½ size of the stimulus 1.2%; hole with pressure around it .6%; diffuse and comes to a point 2.4%; seems to go *in* 2.4%; moves 2.4%; moves then jumps back to stimulated spot .6%; goes to spots previously stimulated .6%.

PUNCTIFORM PRESSURE.

Diffuse, unlocalized, spread 36%; areal 16%; localized 48%.

RADIANT HEAT.

Unlocalized, diffuse, spread 56.2%; wrongly localized 12.5%; well localized 25%; localized subcutaneously 6.2%.

Areal Heat.

Diffuse, spread 55.1%; spread but generally localized 18.4%; distinctly localized 18.4%; ¼ in. circle 2%; dot-like area 4%; changes position 4%.

Punctiform Heat.

Diffuse and spread 31.4%; areal 20%; well localized and punctiform 40%; spread to other areas 2.9%; goes in deep 5.7%.

Electric Heat.

Unlocalized, spread 44.4%; whole arm warm 11.1%; heat radiates off from stimulated spots 11.1%; areal 11.1%; localized 33.3%.

Radiant Cold.

Diffuse, unlocalized 87.5%; cool breeze over that region 4.2%; spread to elbow joint 4.2%; localized 4.2%.

Areal Cold.

Diffuse, spread 38.4%; heat radiated from touch spot 1.5%; not as localized as pressure 2.9%; spread following artery 1.5%; moves 2.9%; goes down like a cone with its base on skin 1.5%; not as deep as pressure but not on the skin 1.5%; clearly localized 50%.

Punctiform Cold.

Diffuse, spread 28.2%; wrongly localized 6.5%; becomes two points 2.2%; goes in deep 4.3%; whole arm cold 2.2%; area 6.5%; areal coming to a point 2.2%; punctiformly localized 45.6%.

Electric Cold.

Diffuse 27.2%; cold radiating off from a spot 9%; sharply localized 54.5%; can't tell 9%.

Punctiform Pain.

Diffuse, spread 33.3%; areal 2.2%; clearly localized 64.4%.

From this table it is seen that punctiform pain gives the greatest per cent of clearly localized after-sensations, and, that the percentage of clear localization decreases and that of diffuseness and spreading increases in the following order: electric cold, punctiform cold, punctiform pressure and areal cold (almost identical), punctiform heat, electric heat, areal pressure, areal heat, radiant heat and radiant cold. It is therefore evident that punctiform stimuli give more clearly localized after-sensations than areal and that with the exception of the radiant form, cold is more easily located than heat.

### TABLE XVI.

PERCENTAGE OF THE MANNER OF APPEARANCE OF SECONDARY AFTER-SENSATIONS.

Areal Pressure.

"Wells up" 8.4% (suddenly 3.6%); increases gradually 22.1%; comes crescendo as a pulsation from within 3%; comes suddenly 25.1%; comes gradually tingling and beating 3.6%; comes from within, i. e. no contact

6%; comes like a twinge 3.6%; in waves 6%; waves from within 1.8%; comes up more quickly than dies down 1.2%; diffuse and coming to a point 2.4%; returns on a full pulsation 3%; can't be sure 10.8%; comes from within in connection with the pulsation 3%.

PUNCTIFORM PRESSURE.

Suddenly 32%; quite sudden 4%; gradually 44%; came from below in a quick throb 4%; impossible to tell 16%.

RADIANT HEAT.

Comes suddenly 6.2%; "wells up" slowly 31.2%; gradual return 25%; comes in waves 25%; impossible to tell 12.5%.

AREAL HEAT.

Suddenly 14.3%; slowly, gradually 57.1%; comes in waves 18.4%; comes in streaks 8.2%; moderately gradual 2%.

PUNCTIFORM HEAT.

Suddenly, quickly 31.4%; quite suddenly 2.8%; "wells up" 5.7%; gradually, slowly 60%.

ELECTRIC HEAT.

Comes suddenly 55.5%; gradually 44.4%.

RADIANT COLD.

In markedly recurrent waves 75%; gradually 20.8%; a cool breeze coming to a point from all directions 4.2%.

AREAL COLD.

Suddenly 38.2%; slowly, gradually 44.1%; in gradual waves 7.3%; comes from below 4.4%; primary sensation spread and came to a head at the stimulated point 2.9%; in waves 2.9%.

PUNCTIFORM COLD.

Suddenly 34.8%; slowly, gradually 30.4%; areal coming to a point 4.3%; in waves or pulses 15.2%; pulsates with the breathing 4.3%; comes in throbs 6.5%; impossible to tell 4.3%.

ELECTRIC COLD.

Gradually 45.4%; suddenly 54.5%.

PUNCTIFORM PAIN.

Slowly, gradually 42.2%; suddenly, quickly 42.2%; in quick beats 2.2%; in irregular short jabs 6.7%; throbs with the pulse 4.4%; uncertain 2.2%.

The only basis for a comparison of the different stimuli here is with regard to the abruptness of appearance of the returning sensation. Grading them in this respect they take the following order: electric heat, electric cold, punctiform pain, punctiform pressure, areal cold, punctiform cold, punctiform heat, areal pressure, areal heat, and radiant heat.

It is to be seen therefore that, with the exception of cold, punctiform stimuli give more sudden returns than areal, that cold, except electric cold, reappears more abruptly than heat, and that pain and electric stimuli give especially sudden returns.

## TABLE XVII.

### PERCENTAGE OF THE MANNER OF DISAPPEARANCE OF PRIMARY AFTER-SENSATIONS.

AREAL PRESSURE.

Spread and disappear 11.7%; end in tingling 10.1%; go slowly 7.4%; quickly, abruptly 21.8%; scatter 5.1%; pass off in two lines converging toward the wrist .4%; move toward the fingers 1.1%; go to a point and disappear 3.1%; go almost instantly 3.5%; moderately slow disappearance 4.7%; fading gradually 11.3%; ends in tickling .8%; ends in a consciousness of the place .8%; spread gradually and disappear 3.5%; uncertain 14.8%.

PUNCTIFORM PRESSURE.

Disappear gradually 55.3%; go abruptly 42.1%; spread away 2.6%.

RADIANT HEAT.

Rather abruptly 14.3%; disappear slowly and gradually 48.5%; diffuse away 37.1%.

AREAL HEAT.

Go gradually 61.9%; abruptly 6.3%; fairly suddenly 3.2%; persistent, i. e. slow in disappearing, 7.9%; very persistent 7.9%; diffuse away gradually 12.7%.

PUNCTIFORM HEAT.

Shades off into a kind of menthol feeling 4.6%; go suddenly 44.2%; go gradually 51.2%.

ELECTRIC HEAT.

Go suddenly 28.6%; go more gradually 28.6%; quite persistent 14.3%; fade out 28.6%;

RADIANT COLD.

Quick but gradual 11.1%; sudden 2.8%; very sudden 8.3%; fade away gradually 63.9%; impossible to tell 13.9%.

AREAL COLD.

Fading slowly and gradually 62.9%; fade out 11.2%; spread away 5.7%; gradually diffusing 19.1%; suddenly 1.1%.

PUNCTIFORM COLD.

Go gradually 39.6%; go very gradually 31%; spread out and disappear 10.3%; go more suddenly 10.3%; go suddenly 3.4%; can't be sure 5.2%.

ELECTRIC COLD.

Go gradually 42.1%; quite persistent 21%; rather suddenly 36.8%.

PUNCTIFORM PAIN.

Go suddenly 51.9%; disappear slowly and gradually 48.1%.

Such a table indicates that: punctiform pain is the only stimulus which gives a greater percentage of sudden than of gradual disappearances; that heat sensations disappear more abruptly than cold and, that areal forms disappear more slowly than punctiform or electric.

### TABLE XVIII.

PERCENTAGE OF THE MANNER OF DISAPPEARANCE OF SECONDARY AFTER-SENSATIONS.

AREAL PRESSURE.

Goes very slowly 17.3%; goes suddenly 14.3%; moderately abrupt 3%; fading gradually 10.7%; spreads and disappears 14.3%; ends in a vague tingle throughout the entire region 2.4%; disappears in a point 3.6%; moves up arm and disappears 2.4%; spreads and dies out in a scattered tingling 12.5%; uncertain 19.6%.

PUNCTIFORM PRESSURE.

Very gradual disappearance 28%; more sudden 16%; gradual 32%; abruptly 8%; uncertain 16%.

RADIANT HEAT.

Suddenly 6.2%; quickly but gradually 18.7%; moderately gradual 56.2%; uncertain 18.7%.

AREAL HEAT.

Fade suddenly 14.3%; go gradually 65.3%; die away in throbbing 6.1%; spread and rapidly disappear 2%; impossible to say 12.2%.

PUNCTIFORM HEAT.

Suddenly 22.9%; apparently suddenly 20%; less suddenly 11.4%; slowly and gradually 25.7%; very persistent 11.4%; radiate off 5.7%; spread 2.9%.

ELECTRIC HEAT.

Suddenly 22.2%; gradual 11.1%; slow disappearing 11.1%; spread and radiate off 55.5%.

RADIANT COLD.

Wave-like decrease 54.2%; gradual 8.3%; quick but gradual 8.3%; impossible to tell 29.2%.

AREAL COLD.

Persistent, fading gradually 69.1%; fade out in indefinite feeling 14.7%; spread 8.8%; go suddenly 7.3%.

PUNCTIFORM COLD.

Go suddenly 13%; go slowly, persistent, 52.2%; spread away 10.9%; fade out 21.7%; go in deep and disappear 2.2%.

ELECTRIC COLD.

Suddenly 36.3%; quite suddenly 36.3%; gradually 27.2%.

PUNCTIFORM PAIN.

Suddenly 31.1%; quite suddenly 15.5%; slowly 35.6%; turned into an ache 8.9%; left a soreness 4.4%; uncertain 4.4%.

This would seem to indicate that punctiform pain and electric cold show the largest percentage of sudden disappearances; that punctiform sensations disappear more abruptly than areal and, that with the exception of electric heat, the heat stimuli disappear more suddenly than the cold.

### D. *Summary of Combined Numerical, Quantitative, and Qualitative Tables.*

If now, all these tables, numerical, qualitative, and quantitative are considered together and the combined data subsummed under the different stimulus headings the following results are shown.

Areal pressure stimuli are quite favorable for primary after-sensations but relatively less so for secondary. More than a third of their primary after-sensations appeared alone, and this is the greatest proportion obtained by any form of stimulus except radiant and electric heat. The quantitative measurements show that the greater part of these primary after-sensations were of "moderate" duration, and that equal proportions of the remainder were "very brief" and long". As to their manner of disappearance, it is seen that 25% disappeared abruptly,—"rang off" without a process of gradual fading, while most of the remainder faded slowly, or spread away still keeping the character of the original stimulus, or perhaps, ended in a tickling, tingling sensation. 38% of these stimuli gave clear latent intervals (a greater proportion than is given by any other type of stimulus), 54% of which endured less than 1″ and only 16% lasted beyond 30″. A small proportion (5.2%) of secondary sensations made their appearance unpreceded by primary,—a greater percentage, however, than was obtained by punctiform pressure or by the other forms of areal stimulation. Of those secondary sensations which it was possible to measure, about 25% were under 15″ in duration and more than half the remainder were "moderate". About 45% (44.4) reproduced the original quality of the stimulus, the remainder taking the qualities of pricking, throbbing, tingling, tickling, stinging, etc., with a few instances of coolness. In less than 10% of the cases did the quality change. In the matter of intensity, areal pressure gave about equal proportions of mild and intense recalls. About a third of the secondary sensations were clearly localized, the rest being diffuse or spread. About a third, likewise, made their appearance abruptly and a considerable number were said to "come from within". The great majority disappeared by a process of slow fading or scattered tingling. The percentage of recurrences was, with this stimulus, 7.5,—a figure almost identical with the percentage of recurrences of areal cold and much in excess of that of areal heat.

Punctiform pressure, as compared with areal, shows a decrease of 10% in primary after-sensations and of 5% in secondary. It ranks in both cases below the contact temperature stimuli and punctiform pain. A little less than a third of the primary sensations were unattended by secondary. Like the areal form of this same stimulus about 40% of the primary sensations were under 15″ in duration but a greater number (27.6%) were over 60″. This stimulus gave the greatest number of primary sensations under 2″. A large percentage (42%) of "suddenly disappearing" primary sensations were found. This stimulus was also especially conducive to clear latent intervals, giving 30%, of which 20% were "short" and the remainder equally divided between the other two headings. Scarcely 2% (1.9) of the secondary sensations appeared unpreceded by a primary,—a reversal of the general condition that punctiform stimuli are more favorable for this type than areal. [Cf. p. 74 (4).] The measurable secondary sensations gave 40% "long" and equal percentages of the other three durations. A proportion almost identical with that obtained by areal pressure (44%), gave after-sensations qualitatively similar to the stimulus. 16% showed qualitative changes with the sensations of pain, sharpness and cold. The intensity of the secondary sensations was here very marked, ranking third in the order of stimuli and far exceeding the strength of areal pressure. 48% were clearly localized and 36% were diffuse while the remaining 16% occupied a middle ground in being termed "areal". About a third of these secondary sensations made their appearance suddenly as against 44% that came gradually; there were a number of cases in which it was impossible to tell how the sensations made their appearance. About a fourth of them disappeared abruptly,—a greater proportion than is found with any stimuli except pain, electric cold and perhaps punctiform heat. Punctiform pressure gave 11.3% of recurrences.

Radiant heat stimuli gave 76.6% of primary after-sensations,—a percentage slightly above that of punctiform heat, considerably less than areal and much larger than radial cold. The percentage of primary after-sensations alone was 38.3,—the largest obtained from any stimulus. Quantitatively only 4.3% of the primary sensations were found to be of less than 2″ duration and only 21.7% exceeded 60″, the great majority lying therefore between these limits. A very small part of these (14%) disappeared suddenly and the rest diffused slowly. The number of latent intervals was also very small (8%), and these were over 30″ in duration. The percentage of secondary sensations was also small (only 34% as contrasted with 65% for areal heat) and no secondary sensations were obtained without primary. The few secondary sensations that were measurable were of moderate duration. The percentage of qualitative similarity to the stimulus is here considerably reduced, especially if the responses "warm" and "hot" are to be considered qualitatively different. Contrary after-sensations were obtained in 12% of the cases. Only 19% were intense and only 25% clearly localized. A very small number (6.2%) came suddenly, (25% were said to "come in waves", and 31% to "well up"). The same amount, 6%, disappeared abruptly. There were 8.5% of recurrences.

Areal heat gave a percentage of 86.7% of primary after-sensations. The greatest part of these were of more than 15″ duration,—a full 50% (51.6) lasting beyond 60″, and only 3.7% less than 2″. As to their manner of disappearance less than 10% vanished abruptly. In 22.7% of the cases the primary sensations appeared alone (a percentage less than that of areal pressure but greater than cold). The preponderance of primary over secondary sensations is smaller for this stimulus than for any other areal stimulus; the percentage of secondary sensations being in this case 65.3%. Of these secondary sensations 2.7% appeared alone. The percentage of clear latent intervals is 16; two-thirds of these were short and none were long. The quantitative measurements show the secondary sensations considered, to have 18.2% which lasted between 5-15″ and the remainder to be divided between the durations "moderate" and "long" with the greater part "long". Qualitatively these sensations show 35% pure warmth and 8% burning, the rest being reported as smarting, tingling, prickling, with 18% of pressure or touch, and 12% of the opposite temperature. In 22% of the cases the quality changed, 16% being a change to the opposite temperature, and the remainder being an alternation between pressure and heat and heat and throbbing. About 40% of these sensations were intense as against 37% mild, 4% were judged "stronger than the stimulus". More than 50% are recorded as diffuse or spread, as against 18% distinctly localized. Only 14.2% are said to return suddenly, the rest coming back gradually or "in waves" or "streaks". About the same proportion (14%) faded out suddenly, while 65% died out gradually,—6% are said to "go out in throbbing". The number of recurrences was less with areal heat than with any other stimulus, being only 4%.

Punctiform heat gives 74% of primary after-sensations, of which 19% appear alone. A small percentage of the primary sensations (4.2%) are of "very brief" duration, 20.8% last from 2-15″ and the remainder is equally divided between the other two headings. 51% disappear gradually as against 41% which "ring off" suddenly, while 5% is said to "shade off into a menthol feeling". Secondary after-sensations appear for 60.3% of the stimulations; 27.6% being preceded by a clear latent interval, and 5.2% coming unattended by a primary sensation. The durations of the latent intervals are equally divided between short and long; and the durations of the secondary sensations are all over 15″, 36.4% being over 60″. Qualitatively more than 50% reproduce the original stimulus (if heat and warmth are to be ranked as the same), the rest are reported as "diffuse pain", "menthol feeling", "tingling", "warm pressure" and "prickling". About 12% change their quality, alternating heat with touch or with the menthol feeling. 34% are called mild as against 40% intense, 3% were spoken of as "stronger than the stimulus" and 6% as "painfully warm". 40% were localized punctiformly while 31% seemed diffuse or spread out, 6% were localized "deep", i. e. subcutaneously. 34% made their appearance suddenly while 60% came gradually, (5.7% are said to "well up"). These sensations show a rather large percentage of abrupt disappearances,—43% going in this way as against 37% of the more gradual type. 13.8% of these sensations show recurrences.

Electric heat gave the smallest percentage of primary sensations obtained by any stimulus and very nearly the smallest percentage of secondary,—58.3% in one case and 37.5% in the other. 20.8% of the primary after-sensations appeared alone but no secondary sensations made their appearance unaccompanied by primary. The quantitative measurements show 42.8% of brief, i. e. 2-15″, primary sensations and 57.1% over 60″. 29% of these die out suddenly as against 43% which fade away gradually. The percentage of latent intervals was about the same as that obtained from radiant heat,—8.3%, and quantitatively they were all long. The secondary sensations gave 31.2% "moderate" and the remainder over 60″. In quality 44% were warm or hot and the remainder gave "smarting", "biting", "sort of burning" sensations with 11% of contrary after-sensations. 33% were said to be intense as against 11% mild; and 33% were clearly localized. The manner of appearance was abrupt for 55.5% and gradual for 44.4%. 22% disappeared suddenly and the rest disappeared gradually or spread or radiated off. Recurrences occurred in 8.3% of the cases.

Radiant cold gives a considerably smaller percentage of primary after-sensations (67.9%) than radiant heat but a noticeably greater one of secondary (45.3%). Necessarily then, the percentage of primary sensations alone is much less than that obtained by cold, being only 18.9%. The quantitative measurements show an identical percentage, for the primary sensations, of "brief" and "moderate" durations (40%) and the remainder were "long". 11% of these disappear suddenly while 75% fade out gradually. As with radiant heat, no secondary sensations appeared unattended by primary and in no case was a clear latent interval reported. No secondary sensations appeared which could be measured. In 17% of the sensations clear cold was reported in 71%, cool; the other responses were "warm" and "rheumatic pain". The percentage of warm returns was 4.2%. Only 12% were spoken of as "strong and definite" and only 4.2% as localized while 62% were reported "faint" and 87% diffuse. 75% of these sensations were said to come "in markedly recurrent waves", 21% came gradually and 4% "like a cool breeze", so that none seemed to show that abruptness of appearance characteristic of some forms. 54% showed also a wave-like *decrease*. The percentage of recurrent sensations was 7.5 as against 8.5 obtained by radiant heat. .

Areal cold showed the highest percentage of primary after-sensations (92.7%) and next to the highest percentage of secondary (70.8%). Comparatively few primary sensations therefore appeared alone (21.8%). This stimulus gave also, the highest percentage, with the exception of electric heat, of primary sensations with long duration (52.1%), while, like areal heat, the percentage under 15″ was very small (6.2% "very brief" and 8.3% "brief"). Practically all of these fade out or spread away gradually (1.1% going suddenly out). The percentage of latent intervals was 11.5%, half of which were of long duration and the other half equally divided between short and moderate. A small percentage of secondary sensations were unpreceded by primary (2.1%). 73.1% of the secondary sensations lasted beyond 60″ and none of the remainder endured less than 15″. Qualitatively 40% were described as identical with the stimulus, 10% gave cold plus contact and the rest were variously described as tingling, moist, wet and heavy, tickle, cool, cold and wet, and throbbing. In about 11% of the cases the quality changed, 1.5% giving the contrary sensation, and the others mainly alternating cold and pressure. This stimulus gave also the strongest after-sensations, 85% being intense with only 7% mild. 50% were clearly localized as against 38% which were not. 38% came suddenly while 51% made their appearance gradually. Only 7.3% disappeared suddenly. The percentage of recurrences was 7.3.

With punctiform cold the percentage of primary after-sensations was 80.6,—the highest obtained for any punctiform stimulus except pain. In duration the percentage over 60″ was less than that found for punctiform heat (40.5%) but the percentage of moderate durations is larger (40.5%); 18.1% lasted less than 2″, a percentage nearly twice that obtained for punctiform heat under this heading. Only 14% of these sensations disappeared abruptly. 20.8% of the primary sensations appeared alone. The percentage of secondary sensations was 63.9, of which 4.2% appeared alone, and 25% were preceded by latent intervals (20% of these being "brief" and the remainder equally divided between "moderate and long"). Quantitatively, the secondary sensations gave percentages very similar to those of areal cold (31.2% moderate and 68.7% long). 61% reproduced the original quality of the stimulus while 2.2% gave "burning cold"; the remainder were spoken of as "cool itching", "cool wave", "cold and pressure", "faint rheumatic pain", "cold tingle", "pricking", "stinging", "cold and touch", "cold and wet", "tingling". The only change in quality was where cool tingle changed to pure cold (2.2.%). 69% of these sensations were intense and 28% mild. 45% were clearly localized as punctiform spots, 28% were diffuse and 6% areal. 34.8% came quickly; while in their manner of disappearance 13% went suddenly while 85% faded out or spread away. The percentage of recurrences was enormously in excess of anything obtained by the other stimuli, being 26.4.

Electric cold gave a percentage of 59.3 primary after-sensations of which 18.5 appeared alone. In duration, the primary sensations all exceeded 2″, the greatest number lasting between 5-60" (33.3% "brief", 41.7% "moderate", 25% "long"). Their manner of disappearance was rather sudden in 37% of the cases. The percentage of secondary sensations was 40.7, of which 7.4 were preceded by a latent interval, although this interval was not measurable. Secondary sensations never appeared unattended by a primary. Half of the secondary sensations were of moderate duration and the remainder divided between brief and long with more long than brief. In quality, electric cold reinstated the original experience in 82% of the cases, while the remainder was divided between sensations of pricking pain and cool tingle. 18% of changes in quality was shown, 9% being a change to the contrary sensation and 9% a change from cold to pain. 54% were strong as against 18% mild; and 54% were localized while 27% were called diffuse. 54.5% appeared suddenly, and 73% disappeared in the same manner, while the remaining 45.4% and 27% were gradual. The percentage of recurrences was 7.4%.

With punctiform pain, the percentage of primary sensations is exceeded only by areal cold, being 85.2. A relatively small percentage (19.7%) appeared alone. In duration, 50% were longer than 60″ and none were less than 2″ (19.4% brief and 30.5% moderate). This stimulus gave the greatest percentage of secondary sensations (73.8%), as well as the greatest percentage of secondary sensations alone (8.2%). The percentage of clear latent intervals was 29.5 and the quantitative measurement of these showed 58.3 to be over 30″ and 33.3 to be brief. The quantitative measurements of the *secondary* sensations showed none to exist under 2″, the entire amount being almost equally divided among the other three headings. In quality 49% reproduced the stimulus, the remainder giving pain and pressure, sharp contact, sharp beating, prickling and throbbing, general ache, pressure and ache, and pressure and tingle. This stimulus showed the greatest percentage of change in quality (usually pressure or touch alternating with pain or else pain changed to prickling or throbbing). About 60% gave strong, steady pain while only 31% were called faint; and 64% were localized clearly as against 33% diffuse or spread out—and this is the largest percentage of exact localization obtained by any stimulus. With regard to the manner of appearance the reports of "gradual" and "sudden" gave relatively close percentages (42.2% and 51%); while 47% disappeared quickly and 36% were persistent. The percentage of recurrences was 13.1.

It is therefore to be seen that with regard to [I] areal and punctiform stimuli of the same type: (1) areal stimuli are more favorable for the production of primary sensations as shown by, (a) the relative number obtained (with the exception of pressure), (b) the number of primary sensations unattended by secondary, (c) their greater duration and (d) their more gradual disappearance; (2) areal stimuli give also the greatest proportion of secondary after-sensations but; (3) punctiform stimuli give a greater percentage of latent intervals and; (4) secondary after-sensations alone (with the exception of pressure, in both cases). (5) Punctiform stimuli give a greater proportion of recurrences. (6) There is no striking difference between areal and punctiform stimuli in the duration of either the secondary sensation or the latent interval. But qualitatively, it is seen that punctiform stimuli (7) more frequently reproduce the identical quality of the stimulus, (8) give no contrary temperature sensations, (9) are less intense (with the exception of pressure) but, (10) are more clearly localized and, (11) make their appearance and disappearance more abruptly than areal.

[II] The relations of heat and cold show that: (1) cold (with the exception of radiate) gives a greater percentage of primary sensations than heat, and that: (2), also with the exception of radiate cold, these sensations have a greater duration. (3) Heat, on the contrary, gives the greater percentage of primary after-sensations alone. (4) The percentage of secondary sensations is greater for cold, (5) which also gives a greater percentage of latent intervals, and (6) secondary after-sensations alone. (7) Quantitatively, the cold sensations show a greater duration. (8) Cold more frequently reproduces the quality of the stimulus, and (9) shows less qualitative changes, including contrary after-sensations. (10) Cold is, with the contact stimuli, more intense, and (11) with the exception of radiate cold, is more clearly localized. (12) Again with the exception of radiate cold, the returns are more abrupt, and (13), this time excepting electric cold, the manner of disappearance is more gradual.

[III] Punctiform pain is more nearly akin to the areal stimulations in: (1) its percentage of primary after-sensations, and (2) the length of their duration as well as (3) in the proportion of secondary sensations obtained. But, it follows the laws of punctiform stimuli in: (4) the number of primary sensations appearing alone, (5) the abrupt disappearance of primary sensations, as well as, (6) the percentage of latent intervals, and (7) of secondary sensations appearing alone. Like the punctiform stimuli, also, it gives (8) a large percentage of qualitative similarity of recall, although it shows a greater proportion of qualitative change than is found with the punctiform temperature sensations. (9) In intensity its percentage is more nearly like that obtained by areal stimuli, but, it follows punctiform rules in its (10) clear localization, and (11) its abruptness of appearance and departure.

## *E. Corneal Pain.*

A limited number of experiments were made on the after-sensations of corneal pain; the author serving as the only subject.

For these experiments, a camel's-hair brush, carefully sterilized, was applied to the surface of the cornea with sufficient force to cause a clear sensation of pain.

The results are given below.

A. NUMERICAL TABLE.

| | |
|---|---|
| 1. Stimulations | 25 |
| 2. Prim. Aft. Sens. | 24 |
| 3. Secd. Aft. Sens. | 22 |
| 4. Prim. Aft. Sens. Alone | 2 |
| 5. Secd. Aft. Sens. Alone | 0 |
| 6. Latent Intervals | 19 |
| 7. Recurrences | 10 |
| 8. No. Aft. Sens. | 1 |
| 9. Percentage Prim. Aft. Sens. | 96% |
| 10. Percentage Secd. Aft. Sens. | 88% |

B. QUANTITATIVE TABLE.

| | |
|---|---|
| Duration Prim. Aft. Sens. | |
| Very Brief | 9—42.8% |
| Brief | 10—47.6% |
| Moderate | 2— 9.5% |
| Long | 0 |
| Duration Latent Interval. | |
| Short | 4—21 % |
| Moderate | 11—57.9% |
| Long | 4—21 % |
| Duration Secd. Aft. Sens. | |
| Very Brief | 2—10.5% |
| Brief | 11—57.9% |
| Moderate | 6—31.6% |
| Long | 0 |

C. QUALITATIVE TABLE.

1. Quality. 12 fine pricking, no contact, 8 sharp prick, 2 fine sting.
2. Change of Quality. 5 end in contact sens.
3. Intensity. 10 intense, 2 mild, 2 strong, 8 stronger than stimulus.
4. Localization. all well localized, 12 finer than stim.
5. Manner of Appearance. 19 sudden, 3 gradual.
6. Manner of Disappearance.
    (a) Prim. 13 sudden, 9 quite sudden, 2 gradually.
    (b) Secd. 13 sudden, 2 quite sudden, 2 gradual, 5 end in a contact sensation.

These figures seem to give results remarkably definite and unequivocal, but as they represent an individual report it is not fair to compare them with the *average* percentages obtained from other stimuli.

It appears, however (1) that the percentage of primary and secondary sensations, as well as that of latent intervals and recurrences, is very large; (2) that the primary sensations are all under 60″ in duration, (3) that over 50% of the latent intervals are of "moderate" duration, with the remainder equally divided between "short" and "long"; and (4) that more than half the secondary sensations are "brief", with 30% "moderate", and the small remainder under 60″. (5) In quality, they are described as fine pricking, sharpness or a fine sting: (6) About 25% end in a contact sensation, but, that is the only change of quality reported. (7) In intensity, all but 9% are strong, and 37% are called stronger than the stimulus. (8) They are all well localized, 64% being said to be finer or more punctiform than the stimulus. (9) 86% come suddenly, while (10) 91% of the primary sensations go abruptly, and (11) 68% of the secondary.

It can now be seen that corneal pain follows the laws of the numerical percentages obtained from pricking pain. Quantitatively, the primary and secondary sensations (as well as the latent intervals although in a lesser degree), are shorter than those of pricking pain. In quality, corneal pain more frequently reproduces the original stimulus, and the intensity seems somewhat greater than with pricking pain, but the two are closely similar in the remarkable accuracy of localization, and the abruptness of appearance and departure.

## IV. COMPARATIVE REVIEW.

We have found that in some of the more incidental descriptions, of the relevant literature, it is hard to say whether a reference to the primary or secondary phenomena is intended. It seems clear, however, that the primary after-sensation of pressure is indicated by Kottenkamp and Ullrich, Funke, Blix, Clark, Krohn, Pillsbury, Henri, Parrish, and by von Frey and Kiesow in their mention of the persistence of sensation after a skin deformation, and, that Donaldson's reference is to the primary temperature sensations.

The descriptions given by Goldscheider, Urbantschitsch, etc., of the primary and secondary sensations and of the latent interval apply perfectly to the phenomena obtained by us. These authors found, as did we, that both sensations may appear or either alone.

### REGIONS BEST SUITED TO THE PRODUCTION OF AFTER-SENSATIONS.

It seems to be generally recognized that the strength and clarity of the after-sensations vary with the region stimulated. We accordingly made a topographical survey of the entire body, with two subjects, to find out if the regions most favorable for the production of after-sensations would show any correspondence with the recognized areas of greatest sensitivity. The results obtained by pressure, temperature, and pain stimulations are given below and while admittedly inexact and unsatisfactory would seem to indicate some such general correspondence.

#### *Pressure.*

Subject X.

Forehead, breast and palm were the most favorable, giving strong and persistent primary and secondary sensations, and distinct latent intervals. Lips, cheek and finger-tips also produced after-sensations that were very clear and strong and had definite latent periods.

There appeared to be after-sensations from stimulations on the abdomen, but the subject believed them confused with sensations from the viscera.

There were moderately intense returns from stimulations on the back.

The ball of the thumb, upper and lower arms, thighs, and the dorsal surface of the lower legs were about equally sensitive.

The volar lower leg seemed to be the region least sensitive to after-sensations, giving no clear latent period and being of faint intensity.

Subject VII.

Face by far the most sensitive.

Palm gave very vivid after-sensations.

Arm and leg about the same and fairly sensitive.

Chest moderately sensitive.

Very few after-sensations obtained on the back.

Six subjects tested on face, hands, and forearm.

Face generally the most sensitive. Palm gave intense and very persistent after-sensations.

Volar side of forearm rather more favorable than dorsal.

Krohn's figures are based on the persistence of pressure sensations; and we would agree with them in that we find pressure sensations to endure longer on muscular surfaces, like the calf of the leg, than on those regions like the shins and ankles where the bones more nearly approach the surface.

### *Heat.*

Subject X.

Forehead and palm gave very clear recalls.

Back of shoulder quite favorable.

Arm, dorsal and volar, moderately favorable.

Practically no after-sensations obtained from stimulation on the thighs.

Subject VII.

Lips and elbow gave very clear after-sensations.

Forehead, cheeks, and palm moderately favorable.

Foot and chest quite sensitive to after-sensations.

Leg, volar and dorsal, poor in after-sensations.

Six subjects tested on face, hands, and forearm.
  Forehead and lips favorable.
  Volar forearm rather better than dorsal.

### *Cold.*

Subject X.
  Forehead and back of neck gave especially clear recalls.
  Back of hand better than palm.
  Cheeks only moderately favorable.
  Legs and arms quite sensitive and about equally so.

Subject VII.
  Forehead and chest favorable.
  Forearm, foot, palm, and back of hand fairly good and about equal.
  Volar surface of elbow very good.
  Back fairly sensitive.

Six subjects tested on face, hands, and forearm.
  Forehead very favorable.
  Palm fairly good.
  Volar and dorsal surface of forearm moderately sensitive.

### *Pain.*

Subject X.
  Face and breast favorable for the production of after-sensations.
  Arm and back of shoulder gave quite clear after-sensations and were about equally favorable.
  Legs gave very few and indistinct after-sensations.

Subject VII.
  Cheek and lips gave very strong after-sensations.
  Back quite favorable.
  Upper and forearm moderately favorable and about equal.
  Palm poor in after-sensations.

Six subjects tested on face, hands, and forearm.
  Face most sensitive.
  Volar and dorsal surface of forearm quite good and about equally favorable.

## CONDITIONS BEST SUITED TO THE PRODUCTION OF AFTER-SENSATIONS.

No attempt has been made in this study to measure with exactness the relative value of different conditions of stimulation—such as intensity duration etc.—for the production of after-sensations, so we have no basis for a satisfactory comparison with the results of Goldscheider, Thunberg, etc. Assembling, however, what data we have, *it can be said that there seems to be a middle ground, both of duration and intensity, within which the after-sensations make their appearance most readily and most clearly.*

With pressure stimuli, it was found that (1) with slow impact, faint intensity, and long duration all sensation tended to be lost during the stimulation, probably as a result of adaptation, so that the removal of the stimulus, if it was effected smoothly, could pass unnoticed. (2) With strong pressure and long duration, the stimulus could likewise be removed unnoticed at the moment, leaving a sensation similar to the stimulus-sensation. There was left, in such cases, however, a clear skin depression and von Frey's contention that the consequent pressure image is dependent on the rapidity with which the skin recovers from this depression is here, perhaps, the best explanation. Such cases are on a par with the common illusions of pressure from a hat-band or from a coin pressed on the forehead, and, might, in a sense, be said to be no after-sensation at all in as much as the resulting skin depression is actually causing a continuous pressure on the subcutaneous tissues. Von Frey's further assertion that the "after-enduring pressure sensations" did not make their appearance with weights of minimal intensity, i.e. those too light to cause a skin depression, would, perhaps, since these stimuli were of "not too brief duration", be explained under (1), i.e. as the result of adaptation. (2) With a less intense stimulus, but with a very long duration the sensation shows a tendency to die out during the stimulus, supposedly as a result of adaptation, and to remain absent for a time after the removal of the stimulating object then to reappear after the manner of a secondary sensation. This seems to be the order of phenomena described by Spindler, who left his weights on the skin 5″-10′. (3) Goldscheider found that primary and secondary sensations separated by a latent interval made their appearance even with stimuli close to the threshold. We, have found this to happen occasionally with weak stimuli and brief duration, but these conditions were always attended by two objections, first, that these stimuli were so near the perceptual limen that their appearance and disappearance were liable to be confused by oscillations of attention, and second, that such light touches often aroused the tickle sensations which quite changed the character of the experiment. (4) Too strong a stimulus, however brief, would apparently cause a bruise the aching quality of which obscured the pressure sensation. (5) Rate of impact is of course closely bound up with intensity but it was found that rapid impact gave better results than slow, apparently because of the fact, that the skin was more apt to adapt itself to the stimulus if it was applied gradually, and the full value was, accordingly, not appreciated. It seems, therefore, that quite strong, relatively brief, and rapidly applied stimuli are best suited to produce the after-sensations of pressure. This would in a general way agree with the results of Goldscheider and Thunberg, who found that there were certain optimal conditions within which the after-sensations made their appearance most definitely, and that these optimal conditions occupied a middle range both of intensity and duration.

Dresslar found that by tickling the region about to be stimulated, so as to bring more blood to the surface, the subsequent after-sensations of pressure were stronger and more definite. We experimented with this method on two subjects and found that the strength and persistence of the *primary* after-sensation would seem to be somewhat increased by this means, but that it had no apparent effect on the *secondary* sensation. This method was discarded, however, on account of the difficulty in getting rid of the tickle sensations aroused, or of the itching which was frequently set up thereby. We tried also the effect of increasing the blood supply in a given region by binding the arm about 5 cm. above the point of stimulation. (2 subjects were used.) The after-sensations resulting from pressure stimuli under these conditions were described as "duller" and somewhat more diffuse than those normally obtained, but the stricture of the bandage and the unpleasant effect of the increased blood pressure made it difficult to attend closely to the pressure sensations *per se.* Rubbing the skin was found the best method of increasing the capillary blood supply without the introduction of distracting sensations; and by this method it was found that the after-sensations of pressure were slightly facilitated, especially if the temperature of the room was such that the arm was slightly cold-adapted. Warming or cooling the skin by immersion in water of 10°C. and 46°C. seemed to detract from the clear definition of the after-sensation, rendering it duller and more diffuse.

Donaldson and Hall speak of the vivid persistence of the after-sensation (primary) of a moving point. We tested each of our 6 subjects by this method and all reported the astonishing clearness of the subsequent sensation. This seemed to fluctuate in parts throughout its length—the first third sometimes standing out most clearly, and sometimes the last quarter being most insistent, and this arrangement made it difficult to say whether the sensation on any part dropped out entirely and again returned, or whether it was simply a decrease in intensity enhanced by the contrast of an increase in intensity on another part. It was very hard to prevent a skin-irritation by this method, too strong a stimulus causing a welt to arise.

Later a more detailed series of experiments was made on three subjects, to test the relative persistence of the sensations of a point moving over a given distance as compared with the after-sensation resulting from a linear stimulus of the same length. Strips of hard rubber 1 mm. in width and varying in length 2-10 cm. were used for the pressure experiments. These were provided with a handle in the center which allowed them to be applied with an even pressure upon the surface of the forearm. The second stimulus was given with a wooden point, 1 mm. in diameter, which was drawn for an equivalent distance along a neighboring surface. The method of thermal stimulation was the same, except that here the strips and point were of brass and warmed or cooled as in previous experiments. Space does not permit a detailed account of these tests, but summarized briefly they resulted as follows: With pressure as the stimulus, it was found that with all three subjects tested the after-sensations of the moving point produced a clearer and more persistent after-sensation, both primary and secondary, than could be obtained by a linear stimulus. With heat as the stimulus the results were quite opposite, the linear stimulus seeming to call out more consistent after-sensations than the other, except in the case of the two smallest lines—i.e. 2 and 4 cm.—where no perceptible difference was noted. With cold one subject obtained her best after-sensations from the moving point, a second distinctly favored the linear stimuli while the results of the third were more or less equivocal, but appeared rather more in favor of the linear form.

With temperature stimuli in general, it was found that the best results were obtained where the stimuli were of such an intensity and endured for so long a time as to give a clear temperature sensation. With too intense stimuli, however brief, a painful or unpleasant quality made its appearance and complicated the results; and the same thing happened if a less intense but still strong stimulus was left too long in contact with the skin. If the intensity were moderate but the duration long both the phenomenon of adapation and the objective change in temperature of the stimulus itself entered in. If the stimulus was strong without being painful (a condition easy to be obtained with cold) the primary sensation tended to show itself clear but so persistent as to obscure any possible secondary sensation. This is in accordance with Dessoir's findings. The best results were, therefore, obtained by stimuli which were of sufficient intensity to give a clear temperature sensation without a painful or unpleasant tone, and which endured only a sufficient length of time for the sensation to be clearly perceived, this apperception-time varying, of course, with the stimulus and the area stimulated.

Binding and tickling the skin were subject to the same difficulties with temperature stimuli as with pressure (although to a somewhat less degree) and the resulting after-sensations showed the same traits.

Warming and cooling the skin, while it decreased the strength of the primary after-sensations of the same stimulus and increased that of the opposite, after the manner of sensation contrast, still gave both primary and secondary sensations which seemed to be duller and less evident.

Rubbing the skin appeared, as with pressure, slightly to "brighten up" the after-sensations.

Dessoir states that the primary after-sensations were stopped by the opposite, and reinforced by the same stimulus, and these facts we easily verified.

We never succeeded in arousing after-sensations on temperature spots by tapping—a rare phenomenon which Goldscheider describes as occasionally taking place; although it must be admitted the number of cases where the temperature sensations themselves were thus mechanically called out was very small.

With pain, those stimuli had to be avoided that were intense enough to bring blood or to cause a definite puncture, for here. the soreness of the actual wound entered into the subsequent sensation. Too long a duration also tended to bring out this objective soreness. A relatively slow impact was found more satisfactory than one faster, in that it gave the subject time to discriminate the moment of actual pain from "the feeling of sharpness" and thus permit a stimulus of the proper intensity to be given.

Binding, warming and cooling, and, in this case, rubbing the skin detracted from the vividness of the recall. It was noticed that in some cases where the skin had been cooled and then stimulated by a prick, a recurrence of the pain sensation occurred after the skin had returned to the normal—or approximately normal—temperature.

### *Skin Anæsthetised.*

We have tested the after-sensations of different stimuli on the anæsthetised skin with 8 subjects (3 being instructors and 5 graduate students in the department of Psychology).

The method was as follows. A normal unshaved skin area was selected on the volar forearm and marked out with analine dye, and this area was then sprayed with ethyl chloride until it was anæsthetic to the prick of a needle. When the white frost had evaporated the stimuli were applied as in the preceding experiments, care being taken here not to let them overlap the normal region.

The results are given below.

### *Pressure.*

Subject I.

Sensitivity is lost for superficial prick, contact and light pressure, as well as for the mild degrees of temperature. It is retained for cotton-wool, and the deep sensibility seems to be unaltered. In many cases, the primary sensation drops out with or before the removal of the stimulus. The latent intervals vary from 5-20″. All sensations are described as deep or tendinous and dull in quality. With intense stimulations a severe, deep-seated pain made its appearance, it came suddenly and usually after a latent interval. Accuracy of localization somewhat better than normal; direction of error the same.

Subject VII.

Surface sensibility lost for everything but cotton-wool. Deep sensibility unaltered. Pressure after-sensations obtained but much less clear and vivid than on normal skin. Severe pain from intense stimulation not found, but this was not expressly tested for. Accuracy of localization very nearly normal.

Subjects VIII, IX, X, XI, XII, VI.

All experienced the loss of all forms of touch, etc., except with cotton-wool, but were unable to be sure of any secondary after-sensations.

### *Cold.*

Subject I.

Insensitive to faint and moderate cold. Two cases of secondary after-sensations. Relatively long intervals, 20-60″. In quality, cold sometimes mixed with slight pain; well localized. With intense stimuli frequent appearance of a very distinct and intense pain, sometimes with and sometimes without slight cold, located deep down below the point stimulated. This pain is occasionally projected.

Subject VIII.

Insensitive to mild and moderate cold. With strong stimulations a period of no sensation intervened and then a stinging pain, like the pain of the anæsthetic.

Subject VII.

Insensitive to mild temperatures. Apperception time for cold very long,—intensity of the cold less vivid than on normal areas. With intense stimulations there results a *very* strong deep pain with no temperature in it.

Subject IX.

Insensitive to weak stimuli. With strong stimuli gets very vivid, intense pain which is projected from the middle forearm to the wrist.

Subject X.

Insensitive to weak stimuli. Thinks can obtain recurrent after-sensation of faint intensity. No pain from intense stimulation.

Subject XI.

Insensitive to weak stimuli. Strong stimulation gave little heat then a warm stinging pain, very intense.

Subject XII.

Insensitive to weak stimuli. Gets pressure after-sensations without temperature, these are frequently projected. With strong stimuli gets cold with a slight superficial pain.

Subject VI.

Insensitive to weak stimuli. With strong stimuli gets strong, deep pain without temperature.

### *Heat.*

Subject I.

Insensitive to weak stimuli. A noticeable delay in perceiving warmth with stronger temperatures. With intense stimuli, a strong deep pain usually projected medianly and distally, with or without warmth. The phenomenon is not as marked as cold.

Subject VIII.

Insensitive to weak stimuli. With strong stimuli, a latent period and then a slight heat with a sting that may be either deep or superficial.

Subject VII.

Insensitive to weak stimuli. With strong stimuli got an intense pain but usually some warmth with it.

Subject IX.

Insensitive to weak stimuli but felt something that was either contact or slight pressure. With strong stimuli, got contact (or pressure) and a slight pain below the surface, maybe a little warmth with it.

Subject X.

Insensitive to weak stimuli. With strong stimuli slight burning but no real pain.

Subject XI.

Insensitive to weak stimuli. With strong stimuli, a little heat felt and strong pain.

Subject XII.

Insensitive to weak stimuli. With strong stimuli got a sensation of blunt pressure with a stinging pain in the center of it, and sometimes a dull warm sensation with a pain that is both superficial and deep.

Subject VI.

Insensitive to weak stimuli. With strong stimuli, gets nothing but pressure and slight diffuse warmth.

### *Pain.*

Subject I.

Prick gave a mild pain with a mildly painful after-sensation. Hair pulled gave a slow developing but very persistent pain.

Subject VII.

Prick gave a relatively quite painful sensation, having a long apperception time. Hair pulled gave dull but persistent pain.

### *Summary.*

It would seem that by this process of skin anæsthetisation we have for a short time, largely destroyed the "epicritic" sensibility and put the affected area in a "protopathic" condition more or less complete. Deep sensibility appears to remain intact, under these conditions,—moderate and strong pressure are perceived and can be localized. Many of the characteristics of protopathic sensibility are quite marked,—the intense pain from temperature stimuli, the slow development of these sensations and their diffuseness and tendency to be projected. The perception of superficial touch and prick as well as the mild degrees of temperature—the distinguishing marks of epicritic sensibility—are, quite absent.[1]

When after sensations were obtained they were less vivid and definite than those obtained on the normal skin.

These results are mainly interesting as showing that a protopathic condition more or less complete, can be set up by the use of a local anæsthetic.[2]

### NUMERICAL COMPARISON.

No numerical comparison of the after-sensations from different stimuli is given in the literature so there is no basis here for a comparison with our results.

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[1] The three phases of sensibility observed by Head, Rivers and Sherren to condition the regeneration of a sectioned cutaneous nerve. (1) Deep sensibility, unaltered after such sectioning, provides sensations of deep pressure and admits of localization by this means although the perception of two points as two, is lacking. (2) Protopathic sensibility, first stage of recovery, attends the perception of prick and temperature (spots) although the threshold for both is higher and the response more intense than normal and strongly subject to "radiation" and "reference". Pain is not appreciated below 30-40 on the algesimeter and the hot and cold spots do not respond to stimuli between 26°-37° C. (3) Epicritic sensibility involves the perception of light touch (cotton wool and no. 5 von Frey hairs on shaved areas) and the intermediate degrees of temperature, these being perceived other than in response to the stimulation of hot and cold spots. The tendency to radiation and reference fades out, and the discrimination of the size and shape of the stimulus, as well as the perception of two points as such, is regained.

[2] Since the writing of this thesis a brief paper has come to our notice by Franz and Ruediger[38] on the sensory changes in the skin following anæsthetization by ethyl chloride. The interest of their research and in consequence the points emphasized differed from ours, but their results do not seem to show anything noticeably at variance with what we have found.

Urbantschitsch found that touch (pressure) stimuli gave more recurrences than areal temperature sensations and from table IV it is seen that this is the case in our experiments.

### QUANTITATIVE COMPARISON.

Funke speaks of the great persistence of pain (primary after-sensation) and our tables show 51% over 60″.

Goldscheider found that some temperature points, especially cold, give very long primary sensations and Donaldson found after-sensations from cold spots lasting "several minutes". We have found a large percentage of primary after-sensations from punctiform cold to exceed 60″.

The length of the latent interval is given as 9/10 of a second by Goldscheider, by Thunberg .88-.96″ for pressure and .85″ for thermal stimuli, while Dessoir speaks of it as "about a second" for temperature stimuli and Külpe says the same for heat. With areal heat stimuli we found that 66% were brief, i.e. under 1″, but the average duration of the latent interval for cold and pressure was found to be greater,—approaching more nearly the figures of Urbantschitsch for whom the latent interval varied from 12-25″.

The length of the secondary sensation of pressure is measured by Spindler but his conditions of stimulation are so different from ours that comparison seems useless. Thunberg speaks of his sensations as "brief enduring"; and Urbantschitsch found the after-sensations of warm varying between 4-45″ and cold between 18-60″; and our figures would come between these limits.

### QUALITATIVE COMPARISON.

We find most of Goldscheider's sensations described as identical with the stimulus, with a painful tone if the stimulus was too intense. The quality with both electric and mechanical stimulation is described as "stechende", and Thunberg described his sensations by the same adjective, but notes two types of response—one a "stechende" sensation followed by a second similar to it, and the other where there is only contact in the first sensation but the second is "stechende" in quality. The sensation of pressure or contact followed by pain, which is identified by Goldscheider with his later phenomena, is shown by von Frey to be nothing other than delayed pain. Dresslar variously describes the sensations as sticking, contact, or tickling and notes the slightly painful tone of some recalls. In our experiments the areal pressure stimuli generally gave the quality of "dull pressure" but the punctiform stimuli, which is the form used by Goldscheider and Thunberg, were often described as "sharpness", "prickly", "stinging", "a pain prickle" or "unpleasant sharpness". Preyer speaks of sensations of opposite temperature following after one of the same temperature as the stimulus, and Urbantschitsch reports many cases of these contrary after-sensations. We have obtained such sensations from areal stimuli, which was the form used by Urbantschitsch.

In intensity, Goldscheider, Thunberg and Urbantschitsch speak of "faint" recalls "strong and definite" and those which are described as—"as strong and stronger than the stimulus";—grades of intensity which we have frequently encountered. Goldscheider found that nearly painful pressure stimuli gave painful recalls, while with actually painful stimuli the after-sensations were less so. In our experiments it was found that intense pressure stimuli usually gave after-sensations which were more or less painful, but, it was not noticed that those stimuli which were strong enough to cause pain gave, as a rule, a non-painful recall.

The after-sensations of Goldscheider and Thunberg are said to be well localized, and, we have found a large percentage of exact localizations for punctiform pressure. Dresslar, using more areal stimuli, describes more diffuse recalls, and Urbantschitsch reports many such for temperature, as well as those which spread and radiate. These characteristics have been noticed by us for areal pressure and temperature.

We have no data to compare with Urbantschitsch on the direction of spreading peculiar to the individual or the stimulus, or on the effect on that spreading of a second application of the stimulus. It may be remarked here that the introspections of our subjects show the phenomena of cutaneous after-sensations to be something less definite and exact and therefore more difficult to trace through its various evolutions than was apparently the case with the subjects of Urbantschitsch; his stimuli were considerably larger and this may, perhaps, have had some effect.

In their mode of appearance Goldscheider and Thunberg's phenomena seem to come relatively suddenly but, Urbantschitsch, on the contrary, seems to find more that make their appearance by a process of gradual increasing. Our data would confirm this, in that the punctiform stimuli, which is what Goldscheider and Thunberg used, make their appearance more abruptly than areal.

The manner of disappearance for primary sensations may be either instant or gradual according to Urbantschitsch, Goldscheider speaks of the primary sensations on temperature spots as ending in an indefinite sensation and the secondary sensations of pressure are spoken of by Dresslar as "going instantly". We have data regarding the manner of disappearance, in accordance with that of Urbantschitsch and Dresslar, but have never received exactly such an account of the ending of punctiform temperature stimuli as is described by Goldscheider.

## SUMMARY.

Our findings in this study are of such a nature that we have found a brief review of them almost impossible. We have summarized in detail the results of our main experiments on pp. 55-65, and would refer the reader thereto.

We think we have shown that cutaneous after-sensations are real phenomena and not explainable by imagination, oscillating attention, or the presence of skin and muscle sensations ordinarily passing unnoticed.

We have found that these phenomena, with their various phases of primary and secondary after-sensation, latent interval, recurrences, etc., occur after the application of each of the forms of stimuli employed.

For a statement of the relative importance of these phases and their relation to the different forms of stimulation we refer to the above mentioned summary of pp. 55-65.

An attempt at an exact quantitative measurement of the duration of these different phases has seemed to us unwise, for the reasons given on pp. 37-39. But by grouping them under such headings as "long", "moderate", "brief", etc. (cf. p. 39) we have obtained some comparative data which are summarized on pp. 45-47 and 55-65.

We have found the after-sensations sometimes differing in quality from that of the stimulus (in a few cases even going to such extremes as the "contrary" temperature after-sensations of Urbantschitsch), but more frequently reproducing the same quality. The degree of definiteness with which the after-sensations can be localized likewise differs with the different stimuli, as does also the manner in which they make their appearance and disappear. A comparative summary of these points is given in detail on pp. 47-55 and 55-65.

(We would state that we place less weight on the data obtained from temperature stimuli radially and electrically given than on those secured from any of the other forms of stimulation, for the reason that the number of stimulations given was less, and because with subjects III, V, and VI we were unable to locate "heat spots" electrically, and with subjects V and VI to locate "cold spots" in this manner.)

Our data on the region of the body best suited to the production of after-sensations pretend to only a rough accuracy, but they seem to indicate that there is a general agreement between these and the regions of greatest sensitivity.

Regarding the conditions most favorable to the production of after-sensations we have found that there is a middle ground both in the intensity and in the duration of the stimulus which causes the after-sensations to appear most clearly, since stimuli above or below this introduce factors of adaptation, bruising, skin-deformation, etc. We also tried the effect of increasing the capillary circulation by rubbing, binding the arm, etc., of rendering the skin hot and cold adapted, and of anæsthetising it by ethyl chloride and found that none of these methods added materially to the clearness of the after-sensations.

## PHYSIOLOGICAL EXPLANATIONS.

The most commonly accepted explanation of cutaneous after-sensations is that of Goldscheider who, it will be remembered, accounts for the delay of the secondary sensation by reason of its course through the grey matter of the cord,—the resistance to this path having to be overcome by an intense, i.e. a painful-stimulus or by a *summation* of more moderate stimuli.

Von Frey explained those early cases of Goldscheider's, where a pressure sensation was followed after an interval by pain, by his discovery of pain spots in the neighborhood of pressure spots and of the greater inertia of these pain spots which caused them to be sensed more slowly. This explanation does not however, as Thunberg suggests, account for those primary and secondary "stechende" sensations, qualitatively similar and neither being in the least painful.

Külpe quotes Goldscheider's theory but suggests the centrifugal fibers running in the sensory roots as affording a more simple explanation.

Thunberg thinks the early sensations are due to a direct nerve stimulation and the secondary are conditioned by a sort of intermediary "Zwischenprocess" set up thereby.

Goldscheider's summation theory as such, seems untenable since the discovery, under his own conditions, of secondary sensations from a single induction shock as was made by Thunberg, and Vintschgau and Durig. Goldscheider's further hypothesis of pressure being in itself a series of stimuli, while it is impossible to disprove, becomes even more difficult to understand if it is to be applied, as it apparently must be, to the thermal (especially the punctiform of moderate intensity) after-sensations since reported.

If the existence of centrifugal fibers in the posterior roots shall be proven and their areas of distribution be found to agree with those of the centripetal fibers, Külpe's suggestion will seem to afford an adequate explanation of the process.

Apart from such an hypothesis three types of theory seem possible. (1) An explanation in terms of spinal cord conduction, i.e. to suppose the nervous impulse arising from a given stimulation to be divided somewhere in its course and to make its way to the conscious center by two or more pathways. The primary sensation is aroused at the moment of arrival of that portion coming by the shortest or most direct pathway and the difference in the length of, or preferably in the number of synapses involved in the two pathways accounts for the latent period. (2) To suppose the impulse to reach the cortex by a single channel giving rise on its arrival to the primary sensation. This impulse then to be taken up by associational neurones and carried on to neighboring regions of the somaesthetic cortex thereby arousing additional sensations, much in the manner that the association fibers between the temporal and occipital lobes are supposed to condition the phenomenon of visual-auditory synaesthesia. Both of these hypotheses are subject to the objection that, from what is known of the rate of nerve conduction and of the "Associationszeit" it would appear that the time necessary to traverse even the longest nerve course, or to effect connections between cortical areas is considerably less than the average duration of the latent interval. (3) Unless one can assume such a process as Külpe describes we are led to accept an explanation, like Thunberg's, in terms of the sensory end-organ. The duration of the latent period is here accounted for by the inertia of the sense organ to the kind of stimulus, presumably chemical, set up by the "Zwischenprocess". Such facts as a change in quality and localization (either by spreading or reference) of the secondary sensation could be accounted for by a diffusion of the "Zwischenprocess" about the surrounding region and its consequent action, in some cases, on sense organs of a different type.

It seems therefore, that, here, as in vision, the phenomena of after-sensations are best explained in peripheral terms; but it seems more safe to say that no satisfactory explanation of after-sensations, or for that matter, of any of the cutaneous phenomena, can be obtained until more is known of the anatomy and physiology of the skin.

## *Appendix.*

### After-Sensations from Electrical Stimulation.

For purposes of comparison with Goldscheider's work we attempted, but without success, to reproduce his conditions. We were unable at the time the experiments were made to secure a circuit interrupter of satisfactory rate. The following is a brief summary of our results.

The electric stimulations were given by means of an induction coil supplied by a storage battery. The electrodes were of fine copper-wire and were imbedded in a wooden handle at a distance of 1 mm. from one another. The rate of oscillation was 50 complete vibrations per second, thus giving approximately 10$\sigma$ intervals between stimuli, and, by weighting the oscillator, the intervals could be increased to 20$\sigma$. In order to limit the number of stimuli given, a Wundt Fall Hammer was introduced into the circuit of the primary coil in such a way that only with the fall of the hammer was the circuit closed and the current allowed to pass out through the secondary coil. The length of this period, and in consequence the number of stimuli given, was varied by adjusting the platforms and the counterpoise. In order to overcome the inertia of the oscillator,—which in the brief durations was very noticeable—it was kept constantly in motion by establishing a circuit through the electro-magnate of the coil, which did not include the primary induction coil. Into this circuit a small incandescent lamp was introduced, which offered a greater resistance than that of the Fall Hammer, although allowing the passage of sufficient current to run the oscillator. Accordingly, when the circuit was closed the current would run through the hammer, following the path of lesser resistance. Two subjects were used for these experiments.

Our results with these stimuli were manifestly unsatisfactory, since, in the first place, we were unable to give intervals greater than 20$\sigma$ while Goldscheider's best results were obtained by intervals of from 30-70. The nearest approach we could obtain to his optimal conditions was by giving 4 stimuli with 20$\sigma$ intervals and with this combination, and with one of 6 stimuli with 20$\sigma$ intervals, we obtained our best results. The latent pauses were here quite clear, although of a duration considerably longer than Goldscheider's and, the secondary sensations were sudden, brief, and stinging or pricking in quality. The importance of the spot stimulated was very noticeable,—as many as 15-20 areas being tried, in some cases, before a favorable one was found. When a considerable number of stimuli, i.e. 10-15+, were given a tingling, or the characteristic whirring, sensation was set up which was quite persistent. With less than 3 stimuli, no certain secondary sensations were obtained, but only a limited surface was tested.

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Individual Tables. Numerical.

| Stimulus. | Areal Pressure. | | | | | | |
|---|---|---|---|---|---|---|---|
| Subjects. | I | II | III | IV | V | VI | Total |
| Stimulations | 54 | 56 | 48 | 50 | 50 | 50 | 308 |
| Primary aft. sens. | 38 | 45 | 44 | 49 | 35 | 44 | 255 |
| Secondary aft. sens. | 24 | 30(1)* | 32 | 21 | 25 | 35 | 167 |
| Prim. aft. sens. alone | 15 | 20 | 12 | 28 | 15 | 13 | 103 |
| Secd. aft. sens. alone | 1 | 6 | 0 | 0 | 5 | 4 | 16 |
| Latent intervals | 9(1) | 24 | 20 | 14 | 20 | 31 | 118 |
| Recurrence of secd. aft. sens. | 4 | 2 | 0 | 0 | 9 | 8 | 23 |
| No aft. sens. | 15 | 5 | 4 | 1 | 10 | 2 | 37 |
| Percentage of prim. aft. sens. | 70.4% | 80.4% | 90.8% | 98% | 70% | 88% | |
| Percentage of secd. aft. sens. | 44.4% | 53.6% | 66.6% | 42% | 50% | 70% | |

| Stimulus. | Punctiform Pressure. | | | | | | |
|---|---|---|---|---|---|---|---|
| Subjects. | I | II | III | IV | V | VI | Total |
| Stimulations | 13 | 10 | 0* | 10 | 10 | 10 | 53 |
| Primary aft. sens. | 11 | 9 | | 10 | 6 | 3 | 39 |
| Secondary aft. sens. | 10 | 6 | | 5 | 4 | (2) | 25 |
| Prim. aft. sens. alone | 2 | 3 | | 5 | 2 | 3 | 15 |
| Secd. aft. sens. alone | 1 | 0 | | 0 | 0 | (2) | 1 |
| Latent intervals | 9 | 3 | | 2 | 2 | (2) | 16 |
| Recurrence of secd. aft. sens. | 4 | 2 | | 0 | 0 | 0 | 6 |
| No aft. sens. | 1 | 1 | | 0 | 4 | 5 | 11 |
| Percentage of prim. aft. sens. | 84.6% | 90% | | 100% | 60% | 30% | |
| Percentage of secd. aft. sens. | 76.9% | 60% | | 50% | 40% | (20%) | |

| Stimulus. | Radiant Heat. | | | | | | |
|---|---|---|---|---|---|---|---|
| Subjects. | I | II | III | IV | V | VI | Total |
| Stimulations | 15 | 6 | 6 | 6 | 8 | 6 | 47 |
| Primary aft. sens. | 11 | 3 | 5 | 4 | 6 | 6 | 35 |
| Secondary aft. sens. | 9 | (1) | 1 | 2 | 3 | 1 | 16 |
| Prim. aft. sens. alone | 2 | 2 | 4 | 2 | 3 | 5 | 18 |
| Secd. aft. sens. alone | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Latent intervals | 3 | 0 | 0 | 0 | 0 | 1 | 4 |
| Recurrence of secd. aft. sens. | 4 | 0 | 0 | 0 | 0 | 0 | 4 |
| No aft. sens. | 4 | 3 | 1 | 2 | 2 | 0 | 12 |
| Percentage of prim. aft. sens. | 73.3% | 50% | 83.3% | 66.7% | 75% | 100% | |
| Percentage of secd. aft. sens. | 60% | (10%) | 0% | 33.3% | 37.5% | 16.4% | |

| Stimulus. | Areal Heat. | | | | | | |
|---|---|---|---|---|---|---|---|
| Subjects. | I | II | III | IV | V | VI | Total |
| Stimulations | 20 | 10 | 10 | 15 | 10 | 10 | 75 |
| Primary aft. sens. | 16 | 8 | 10 | 15 | 8 | 8 | 65 |
| Secondary aft. sens. | 11(1) | 0 | 9 | 10 | 8 | 5 | 49 |
| Prim. aft. sens. alone | 4 | 3 | 1 | 5 | 1 | 3 | 17 |
| Secd. aft. sens. alone | 0 | 1 | 0 | 0 | 1 | 0 | 2 |
| Latent intervals | 0 | 3 | 0 | 5 | 4 | 0 | 12 |
| Recurrence of secd. aft. sens. | 1 | 0 | 0 | 1 | 1 | 0 | 3 |
| No aft. sens. | 4 | 1 | 0 | 0 | 1 | 2 | 8 |
| Percentage of prim. aft. sens. | 80% | 80% | 100% | 100% | 80% | 80% | |
| Percentage of secd. aft. sens. | 55% | 60% | 90% | 66.7% | 80% | 50% | |

| Stimulus. | Punctiform Heat. | | | | | | |
|---|---|---|---|---|---|---|---|
| Subjects. | I | II | III | IV | V | VI | Total |
| Stimulations | 10 | 10 | 8 | 10 | 10 | 10 | 58 |
| Primary aft. sens. | 7 | 6 | 3 | 9 | 9 | 9 | 43 |
| Secondary aft. sens. | 6 | 7 | 3 | 8 | 7 | 4 | 35 |
| Prim. aft. sens. alone | 2 | 0 | 0 | 1 | 2 | 6 | 11 |
| Secd. aft. sens. alone | 1 | 1 | 0 | 0 | 0 | 1 | 3 |
| Latent intervals | 3 | 2 | 2 | 5 | 3 | 1 | 16 |
| Recurrence of secd. aft. sens. | 0 | 0 | 1 | 6 | 1 | 0 | 8 |
| No aft. sens. | 2 | 3 | 5 | 1 | 1 | 0 | 12 |
| Percentage of prim. aft. sens. | 70% | 60% | 37.5% | 90% | 90% | 90% | |
| Percentage of secd. aft. sens. | 60% | 70% | 37.5% | 80% | 70% | 40% | |

| Stimulus. | "Electric Heat." | | | | | | |
|---|---|---|---|---|---|---|---|
| Subjects. | I | II | III | IV | V | VI | Total |
| Stimulations | 10 | 6 | 0 | 8 | 0 | 0 | 24 |
| Primary aft. sens. | 2 | 6 | | 6 | | | 14 |
| Secondary aft. sens. | 1 | 3 | | 5 | | | 9 |
| Prim. aft. sens. alone | 1 | 3 | | 1 | | | 5 |
| Secd. aft. sens. alone | 0 | 0 | | 0 | | | 0 |
| Latent intervals | 0 | 1 | | 1 | | | 2 |
| Recurrence of secd. aft. sens. | 0 | 1 | | 1 | | | 2 |
| No aft. sens. | 8 | 0 | | 2 | | | 10 |
| Percentage of prim. aft. sens. | 20% | 100% | | 75% | | | |
| Percentage of secd. aft. sens. | 10% | 50% | | 62.5% | | | |

| Stimulus. | Radiant Cold. | | | | | | |
|---|---|---|---|---|---|---|---|
| Subjects. | I | II | III | IV | V | VI | Total |
| Stimulations. | 21 | 6 | 6 | 4 | 6 | 10 | 53 |
| Primary aft. sens. | 17 | 4 | 5 | 4 | 4 | 2 | 36 |
| Secondary aft. sens. | 13(2) | 2 | 5 | 2 | 2 | 0 | 24 |
| Prim. aft. sens. alone | 2 | 2 | 0 | 2 | 2 | 2 | 10 |
| Secd. aft. sens. alone | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Latent intervals | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Recurrence of secd. aft. sens. | 4 | 0 | 0 | 0 | 0 | 0 | 4 |
| No aft. sens. | 4 | 2 | 1 | 0 | 2 | 8 | 17 |
| Percentage of prim. aft sens. | 80.9% | 66.7% | 83.3% | 100% | 65.6% | 20% | |
| Percentage of secd. aft. sens. | 61.9% | 33.3% | 83.3% | 50% | 16.7% | 0% | |

| Stimulus. | Areal Cold. | | | | | | |
|---|---|---|---|---|---|---|---|
| Subjects. | I | II | III | IV | V | VI | Total |
| Stimulations. | 18 | 14 | 10 | 16 | 20 | 18 | 96 |
| Primary aft. sens. | 15 | 14 | 10 | 16 | 17 | 17 | 89 |
| Secondary aft. sens. | 12(2) | 12 | 10 | 6 | 15 | 13 | 68 |
| Prim. aft. sens. alone | 1 | 2 | 0 | 10 | 3 | 5 | 21 |
| Secd. aft. sens. alone | 0 | 0 | 0 | 0 | 1 | 1 | 2 |
| Latent intervals | 0 | 1 | 0 | 1 | 4 | 5 | 11 |
| Recurrence of secd. aft. sens. | 3 | 0 | 0 | 1 | 2 | 1 | 7 |
| No aft. sens. | 3 | 0 | 0 | 0 | 2 | 0 | 5 |
| Percentage of prim. aft sens. | 83.3% | 100% | 100% | 100% | 85% | 94.4% | |
| Percentage of secd. aft. sens. | 66.7% | 85.7% | 100% | 37.5% | 75% | 72.3% | |

| Stimulus. | Punctiform Cold. | | | | | | |
|---|---|---|---|---|---|---|---|
| Subjects. | I | II | III | IV | V | VI | Total |
| Stimulations. | 10 | 10 | 11 | 11 | 20 | 10 | 72 |
| Primary aft. sens. | 8 | 7 | 10 | 9 | 16 | 8 | 58 |
| Secondary aft. sens. | 7 | 7 | 7 | 9 | 11 | 5 | 46 |
| Prim. aft. sens. alone | 1 | 1 | 3 | 1 | 6 | 3 | 15 |
| Secd. aft. sens. alone | 0 | 1 | 0 | 1 | 1 | 0 | 3 |
| Latent intervals | 1 | 3 | 0 | 5 | 5 | 4 | 18 |
| Recurrence of secd. aft. sens. | 3 | 3 | 1 | 7 | 4 | 1 | 19 |
| No aft. sens. | 2 | 2 | 1 | 1 | 3 | 2 | 11 |
| Percentage of prim. aft sens. | 80% | 70% | 90.9% | 81.8% | 80% | 80% | |
| Percentage of secd. aft. sens. | 70% | 70% | 63.6% | 81.8% | 55% | 50% | |

| Stimulus. | "Electric Cold." | | | | | | |
|---|---|---|---|---|---|---|---|
| Subjects. | I | II | III | IV | V | VI | Total |
| Stimulations. | 10 | 5 | 7 | 5 | 0 | 0 | 27 |
| Primary aft. sens. | 2 | 4 | 7 | 3 | | | 16 |
| Secondary aft. sens. | 1 | 2 | 5 | 3 | | | 11 |
| Prim. aft. sens. alone | 1 | 2 | 2 | 0 | | | 5 |
| Secd. aft. sens. alone | 0 | 0 | 0 | 0 | | | 0 |
| Latent intervals | 0 | 2 | 0 | 0 | | | 2 |
| Recurrence of secd. aft. sens. | 0 | 1 | 0 | 1 | | | 2 |
| No aft. sens. | 8 | 1 | 0 | 2 | | | 11 |
| Percentage of prim. aft sens. | 20% | 80% | 100% | 60% | | | |
| Percentage of secd. aft. sens. | 10% | 40% | 71.4% | 0% | | | |

| Stimulus. | Punctiform Pain. | | | | | | |
|---|---|---|---|---|---|---|---|
| Subjects. | I | II | III | IV | V | VI | Total |
| Stimulations. | 10 | 10 | 11 | 10 | 10 | 10 | 61 |
| Primary aft. sens. | 9 | 8 | 10 | 9 | 6 | 10 | 52 |
| Secondary aft. sens. | 7 | 8 | 8 | 7 | 5 | 10 | 45 |
| Prim. aft. sens. alone | 3 | 1 | 2 | 3 | 3 | 0 | 12 |
| Secd. aft. sens. alone | 1 | 1 | 0 | 1 | 2 | 0 | 5 |
| Latent intervals | 4 | 6 | 2 | 2 | 2 | 2 | 18 |
| Recurrence of secd. aft. sens. | 3 | 1 | 2 | 0 | 0 | 2 | 8 |
| No aft. sens. | 0 | 1 | 1 | 0 | 2 | 0 | 4 |
| Percentage of prim. aft sens. | 90% | 80% | 90.9% | 90% | 60% | 100% | |
| Percentage of secd. aft. sens. | 70% | 80% | 72.7% | 70% | 50% | 100% | |

* ( ) = cases of uncertainty.

* Subject III had never been able to locate "pure pressure spots".

Individual Tables. Quantitative.

| Stimulus. | Areal Pressure. | | | | | | | Punctiform Pressure. | | | | | | | Radiant Heat. | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Subjects. | I | II | III | IV | V | VI | Total | I | II | III | IV | V | VI | Total | I | II | III | IV | V | VI | Total |
| Duration of prim. aft. sen. | | | | | | | | | | | | | | | | | | | | | |
| (1) Very brief, -2″ | 5 | 12 | 0 | 0 | 0 | 11 | 28 | 4 | 0 | 0 | 0 | 0 | 1 | 5 | 1 | 0 | 0 | 0 | 0 | 0 | 1 |
| (2) Brief, 2-15″ | 7 | 0 | 13 | 17 | 0 | 19 | 56 | 3 | 0 | | 2 | 0 | 2 | 7 | 2 | 0 | 2 | 0 | 2 | 1 | 7 |
| (3) Moderate, 15-60″ | 6 | 21 | 13 | 17 | 30 | 6 | 93 | 3 | 4 | | 0 | 2 | 0 | 9 | 2 | 0 | 1 | 1 | 1 | 5 | 10 |
| (4) Long, 60″+ | 5 | 5 | 6 | 8 | 0 | 4 | 28 | 0 | 2 | | 4 | 2 | 0 | 8 | 0 | 3 | 1 | 1 | 0 | 0 | 5 |
| Length of latent interval. | | | | | | | | | | | | | | | | | | | | | |
| (1) Short, -1″ | 1 | 6 | 0 | 0 | 2 | 11 | 20 | 0 | 1 | | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| (2) Moderate, 1-30″ | 2 | 2 | 0 | 0 | 3 | 4 | 11 | 2 | 0 | | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| (3) Long, 30″+ | 3 | 1 | 0 | 0 | 2 | 0 | 6 | 0 | 1 | | 0 | 1 | 0 | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 1 |
| Duration of secd. aft. sen. | | | | | | | | | | | | | | | | | | | | | |
| (1) Very brief, -2″ | 2 | 0 | 3 | 0 | 0 | 0 | 5 | 0 | 2 | | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| (2) Brief, 2-15″ | 0 | 3 | 0 | 0 | 3 | 2 | 8 | 1 | 0 | | 0 | 1 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| (3) Moderate, 15-60″ | 2 | 7 | 0 | 0 | 2 | 9 | 20 | 2 | 0 | | 0 | 0 | 0 | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 1 |
| (4) Long, 60″+ | 2 | 0 | 3 | 0 | 4 | 6 | 15 | 0 | 2 | | 2 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| Stimulus. | Areal Heat. | | | | | | | Punctiform Heat. | | | | | | | "Electric Heat." | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Subjects. | I | II | III | IV | V | VI | Total | I | II | III | IV | V | VI | Total | I | II | III | IV | V | VI | Total |
| Duration of prim. aft. sen. | | | | | | | | | | | | | | | | | | | | | |
| (1) Very brief, -2″ | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| (2) Brief, 2-15″ | 0 | 2 | 0 | 1 | 0 | 0 | 3 | 1 | 1 | 1 | 1 | 0 | 1 | 5 | 0 | 2 | | 1 | | | 3 |
| (3) Moderate, 15-60″ | 2 | 2 | 0 | 2 | 1 | 2 | 9 | 3 | 0 | 0 | 4 | 1 | 1 | 9 | 0 | 0 | | 0 | | | 0 |
| (4) Long, 60″+ | 2 | 1 | 1 | 6 | 3 | 1 | 14 | 0 | 0 | 0 | 1 | 4 | 4 | 9 | 1 | 2 | | 1 | | | 4 |
| Length of latent interval. | | | | | | | | | | | | | | | | | | | | | |
| (1) Short, -1″ | 0 | 0 | 0 | 0 | 1 | 1 | 2 | 1 | 1 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | | 0 | | | 0 |
| (2) Moderate, 1-30″ | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | 0 | | | 0 |
| (3) Long, 30″+ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 2 | 0 | 0 | | 1 | | | 1 |
| Duration of secd. aft. sen. | | | | | | | | | | | | | | | | | | | | | |
| (1) Very brief, -2″ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | 0 | | | 0 |
| (2) Brief, 2-15″ | 0 | 0 | 0 | 0 | 1 | 1 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | | 0 | | | 1 |
| (3) Moderate, 15-60″ | 1 | 0 | 0 | 2 | 1 | 0 | 4 | 1 | 1 | 0 | 3 | 2 | 0 | 7 | 1 | 1 | | 1 | | | 3 |
| (4) Long, 60″+ | 0 | 2 | 0 | 2 | 1 | 0 | 5 | 1 | 1 | 0 | 2 | 0 | 0 | 4 | 0 | 0 | | 1 | | | 1 |

| Stimulus. | Radiant Cold. | | | | | | | Areal Cold. | | | | | | | Punctiform Cold. | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Subjects. | I | II | III | IV | V | VI | Total | I | II | III | IV | V | VI | Total | I | II | III | IV | V | VI | Total |
| Duration of prim. aft. sen. | | | | | | | | | | | | | | | | | | | | | |
| (1) Very brief, -2″ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 2 | 0 | 3 | 0 | 1 | 0 | 0 | 1 | 1 | 3 |
| (2) Brief, 2-15″ | 1 | 1 | 0 | 0 | 0 | 0 | 2 | 1 | 0 | 1 | 0 | 0 | 2 | 4 | 0 | 0 | 0 | 0 | 4 | 0 | 4 |
| (3) Moderate, 15-60″ | 1 | 0 | 0 | 1 | 0 | 0 | 2 | 4 | 1 | 3 | 3 | 1 | 4 | 16 | 3 | 2 | 0 | 3 | 5 | 2 | 15 |
| (4) Long, 60″+ | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 3 | 5 | 2 | 8 | 3 | 4 | 25 | 2 | 2 | 3 | 3 | 1 | 4 | 15 |
| Length of latent interval. | | | | | | | | | | | | | | | | | | | | | |
| (1) Short, -1″ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 2 | 0 | 0 | 0 | 0 | 1 | 1 | 2 |
| (2) Moderate, 1-30″ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 2 | 1 | 0 | 0 | 1 | 1 | 1 | 4 |
| (3) Long, 30″+ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 2 | 4 | 0 | 3 | 0 | 1 | 0 | 0 | 4 |
| Duration of secd. aft. sen. | | | | | | | | | | | | | | | | | | | | | |
| (1) Very brief, -2″ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| (2) Brief, 2-13″ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| (3) Moderate, 15-60″ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 2 | 0 | 1 | 1 | 7 | 1 | 0 | 0 | 2 | 2 | 0 | 5 |
| (4) Long, 60″+ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 5 | 4 | 2 | 2 | 2 | 19 | 3 | 3 | 0 | 1 | 2 | 2 | 11 |

| Stimulus. | "Electric Cold." | | | | | | | Punctiform Pain. | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Subjects. | I | II | III | IV | V | VI | Total | I | II | III | IV | V | VI | Total |
| Duration of prim. aft. sen. | | | | | | | | | | | | | | |
| (1) Very brief, -2″ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| (2) Brief, 2-15″ | 1 | 0 | 3 | 0 | | | 4 | 2 | 1 | 0 | 1 | 1 | 2 | 7 |
| (3) Moderate, 15-60″ | 0 | 3 | 2 | 0 | | | 5 | 0 | 3 | 3 | 1 | 1 | 3 | 11 |
| (4) Long, 60″+ | 0 | 1 | 2 | 0 | | | 3 | 4 | 3 | 4 | 4 | 1 | 2 | 18 |
| Length of latent interval. | | | | | | | | | | | | | | |
| (1) Short, -1″ | 0 | 0 | 0 | 0 | | | 0 | 0 | 0 | 1 | 2 | 0 | 1 | 4 |
| (2) Moderate, 1-30″ | 0 | 0 | 0 | 0 | | | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 |
| (3) Long, 30″+ | 0 | 0 | 0 | 0 | | | 0 | 2 | 4 | 0 | 0 | 0 | 1 | 7 |
| Duration of secd. aft. sen. | | | | | | | | | | | | | | |
| (1) Very brief, -2″ | 0 | 0 | 0 | 0 | | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| (2) Brief, 2-13″ | 0 | 0 | 1 | 0 | | | 1 | 2 | 0 | 1 | 2 | 0 | 3 | 8 |
| (3) Moderate, 15-60″ | 0 | 0 | 2 | 1 | | | 3 | 0 | 2 | 3 | 1 | 0 | 2 | 8 |
| (4) Long, 60″+ | 0 | 0 | 2 | 0 | | | 2 | 0 | 3 | 2 | 0 | 0 | 2 | 7 |

# INDIVIDUAL TABLES. QUALITIVE

## Stimulus. Areal Pressure.

### Subject I.

1—Quality. 8 dull pressure; 4 prickly; 2 tingling, 4 tickling, 2 deep tendinous feeling; 2 contact and pressure, 2 cool.

2—Changes in quality. 1 dull pressure changes to cool and then again to pressure; 3 pressure ends in tickling; a cutaneous feeling that changes to tendon strain.

3—Intensity. 12 delicate; 5 moderate; 7 intense.

4—Localization. 6 sharply localized; 12 diffuse or spreading, 6 limited to a definite area.

5—Manner of appearance. 6 "well up" suddenly; 18 increase gradually

6—Manner of disappearance;—

(a) Primary. 10 disappear suddenly; 10 fade gradually; 9 almost instantly; 9 moderately slow

(b) Secondary. 9 of long duration; 5 moderately sudden; 10 disappear quickly.

### Subject II.

1—Quality. 12 dull pressure; 3 stinging; 1 itching; 2 throbbing; 3 tingling; 5 tickling; 2 strain; 1 soft pressure; 1 cold.

2—Changes in quality. 1 primary sensation flickering, secondary steady, 1 delicate pressure changes to one with sting in it, 1 pressure changes to slight warmth.

3—Intensity. 17 faint; 13 intense.

4—Localization. 6 massive and unlocalized; 12 well localized; 3 rather diffuse; 6 spread; 3 spread in primary but return localized.

5—Manner of appearance. 5 "crescendo", as a pulsation from within; 10 suddenly; 5 "swell up"; 1 can't be sure; 3 come from within, no contact; 6 gradually, tingling and beating.

6—Manner of disappearance;—

(a) Primary. 21 dying out fast; 19 fading gradually; 3 moderately gradual; 1 ends in consciousness of the place.

(b) Secondary. 4 very sudden; 6 fading gradually; 10 fading very slowly, 8 spread; 2 can't be sure.

### Subject III.

1—Quality. 13 distinct pressure; 7 tickling; 6 indistinct tingle; 6 sharp itching.

2—Changes in quality.

3—Intensity. 8 slight; 16 strong; 8 more intense than the stimulus.

4—Localization. 5 localized; 27 diffuse or spread over a surface.

5—Manner of appearance. 5 like a twinge; 6 suddenly; 4 gradually; 17 can't be sure.

6—Manner of disappearance;—

(a) Primary. 9 spread gradually and disappeared; 2 went suddenly; 4 persistent; rest uncertain.

(b) Secondary. 3 gone quickly; 5 persistent; can't tell about others.

### Subject IV.

1—Quality. 6 faintly prickly (as if asleep); 8 feels blunt; 7 tingling.

2—Changes in quality.

3—Intensity. 13 moderate; 8 faint

4—Localization. 9 localized; 6 diffuse; 1 spreads up the finger; 5 spread.

5—Manner of appearance. 5 seem to come from within in connection with the pulsation; 10 in waves; 6 return gradually.

6—Manner of disappearance;—

(a) Primary. 15 quite persistent; 16 spread and disappear; 9 end in tingling; 9 uncertain.

(b) Secondary. 6 spread and disappear; 7 go gradually; 2 suddenly; 6 can't be sure.

### Subject V.

1—Quality. 17 pressure; 8 throbbing.

2—Changes in quality.

3—Intensity. 13 faint; 12 hard and vivid.

4—Localization. 8 a localized area; 13 diffuse; 1 diffuse and then comes to a point; 1 moves then jumps back to stimulated spot; 2 spread

5—Manner of appearance. 3 as waves coming from within; 1 "well up"; 1 like a twinge; 2 came up more quickly than died down; 9 suddenly; 6 gradually; 1 diffuse coming to a point.

6—Manner of disappearance;—

(a) Primary. 15 quickly; 10 spreading; 10 end in vague tingle.

(b) Secondary. 3 disappear in a point; 5 spread and disappear; 5 go slowly; 5 quickly; 4 end in vague tingle through whole region; 5 quite persistent.

### Subject VI.

1—Quality. 15 pure pressure, i.e. no touch; 4 warmth; 4 tingling sensation; 4 cool tickling; 2 slight pressure like pressing on a callous spot; 4 tickle; 2 elastic feeling.

2—Changes in quality. 1 pressure becomes warm; 1 pressure goes away in tingling; 1 pressure fading and cool comes in; 1 tickling followed by light pressure; 1 alternates pressure and cutaneous sensations.

3—Intensity. 13 slight, 9 moderate; 13 stronger than stimulus.

4—Localization. 7 diffuse; 10 localized; 2 felt as half the size of the stimulus; 4 seem to go in; 1 feels like a hole with pressure around it; 2 spread; 1 a tickling, tingling primary sensation which gradually comes to a point, goes and the after-sensation is broad dull pressure like stimulus; 1 dull pressure goes down to a point; 1 ran to spots previously stimulated; 1 tingle and pressure where tingle spreads out over the surface and pressure narrows down to a point; 1 scatters, then gathers to a point; 4 move (2 distally, 2 proximally).

5—Manner of appearance. 5 return on a full pulsation; 7 come from within; 17 suddenly; 3 gradually; 3 diffuse and come to a point.

6—Manner of disappearance;—

(a) Primary. 4 spread; 13 scatter; 1 passes off in 2 lines converging toward the wrist; 3 move toward fingers; 7 go off in tingling; 8 fade rapidly; 8 go to a point and disappear.

(b) Secondary. 4 move up arm and disappear; 7 spread and disappear; 21 spread and die out in a scattered tingling or prickle; 3 disappear in a point

## Stimulus. Punctiform Pressure.

### Subject I.

1—Quality. 4 dull pressure; 1 cold and pressure; 2 prickly feeling; 1 sharp; 1 pressure and soreness; 1 granular feeling.

2—Changes in quality. 1 pressure that changed to sharpness; 1 cold and pressure, cold goes and leaves pressure alone.

3—Intensity. 2 equal to stimulus; 3 mild; 3 distinct; 2 intense.

4—Localization. 6 definitely localized; 4 more areal.

5—Manner of appearance. 3 sudden; 4 gradually; 3 unable to tell.

6—Manner of disappearance;—

(a) Primary. 8 suddenly; 3 fade slowly.

(b) Secondary. 5 die away slowly; 2 quickly; 3 uncertain.

### Subject II.

1—Quality. 4 dull like the original; 1 sharp, painful; 1 mixed with cool.

2—Changes in quality. 1 dies out in pain; 1 cold and pressure, cold gets stronger, then a return like the original.

3—Intensity. 3 like the stimulus; 3 strong.

4—Localization. 4 punctiform, well localized; 1 diffuse; 1 spreads downwards.

5—Manner of appearance. 4 sudden; 1 gradual; 1 uncertain.

6—Manner of disappearance;—

(a) Primary. 6 gradually; 2 more suddenly; 1 spreads.

(b) Secondary. 3 very slowly; 2 more quickly; 1 uncertain.

### Subject IV.

1—Quality. 2 painful itching, 1 prickling; smarting; 1 pressure; 1 pressure and pain.

2—Changes in quality.

3—Intensity. 4 moderately intense; 1 mild.

4—Localization. 2 localized; 3 diffuse.

5—Manner of appearance. 3 gradually; 1 sudden; 1 moderately sudden.

6—Manner of disappearance;—

(a) Primary. 7 gradually; 3 more quickly.

(b) Secondary. 4 persistent, i.e. gradual; 1 disappears suddenly.

### Subject V.

1—Quality. 1 pressure; 2 pain prickle; 1 throbs.

2—Changes in quality.

3—Intensity. 2 fairly strong; 2 mild.

4—Localization. 3 not well localized; 1 diffuse.

5—Manner of appearance. 1 comes from underneath, in a quick throb; 3 more gradual.

6—Manner of disappearance;—

(a) Primary. [illegible] gradual; 2 quickly.

(b) Secondary. [illegible] gone suddenly; 3 fairly gradual.

### Subject VI.

1—[illegible] ure; 1 perhaps pricking pain.

[illegible]

3—Intensity. 2 [illegible]

4—Localization. 2 diffuse. (?)

5—Manner of appearance. Uncertain.

6—Manner of disappearance;—

(a) Primary. 1 gone quickly; 2 more persistent.

(b) Secondary. 2 gone quickly. (?)

## Stimulus. Radiant Heat

### Subject I.

1—Quality. 2 neutral; indescribable sensation; 2 *hot*, 1 little warmth and smarting; 2 warm; 2 cool.

2—Changes in quality;—

(1) Contrary after-sensation. 1 the secondary after-sensation seems to be cold or smarting

3—Intensity. 4 mild; 3 not intense, 2 intense.

4—Localization. 4 well localized; 5 unlocalized.

5—Manner of appearance. 5 "well up" slowly; 3 very gradual return; 1 comes quickly.

6—Manner of disappearance;—

(a) Primary. 2 rather suddenly; 9 diffused slowly.

(b) Secondary. 1 goes quickly; 8 moderately slow.

### Subject II.

1—Quality. 1 warm primary sensation which without diminishing turns cold, etc

2—Changes in quality. Warm primary sensation turns cold and becomes very cold then tickling sensation with heat.

3—Intensity

4—Localization. This sensation is rather diffuse.

5—Manner of appearance.

6—Manner of disappearance;—

(a) Primary. 3 fade gradually.

(b) Secondary.

### Subject III.

1—Quality. 1 (?) faint warmth.

2—Changes in quality.

3—Intensity. 1 (?) faint.

4—Localization. 1 (?) not localized.

5—Manner of appearance. Came in a wave.

6—Manner of disappearance;—

(a) Primary. 5 disappear gradually.

(b) Secondary. Uncertain.

### Subject IV.

1—Quality. 2 peculiar pain or throbbing.

2—Changes in quality.

3—Intensity. 2 not very intense.

4—Localization. 1 goes in deep; 1 spread.

5—Manner of appearance. 2 impossible to tell.

6—Manner of disappearance;—

(a) Primary. All disappeared gradually.

(b) Secondary. 2 impossible to say.

### Subject V.

1—Quality. 1 warm; 1 definite heat wave; 1 indefinite tingling quality.

2—Changes in quality;—

(1) Contrast. 1 space around is cool.

3—Intensity. 2 faint; 1 clear definite.

4—Localization. 1 no localization; 2 wrongly localized.

5—Manner of appearance. 3 came in waves.

6—Manner of disappearance;—

(a) Primary. 2 gone quickly; 4 diffuse away.

(b) Secondary. 3 sink quickly, but gradually.

### Subject VI.

1—Quality. 1 faint warmth.

2—Changes in quality.

3—Intensity. 1 mild.

4—Localization. 1 diffuse.

5—Manner of appearance. 1 gradual.

6—Manner of disappearance;—

(a) Primary. 1 quick; 5 gradual.

(b) Secondary. 1 gradual.

## Stimulus. Areal Heat

### Subject I.

1—Quality. 4 smarting; 2 burning; 1 partly tactual; 2 prickly, 2 cool menthol feeling.

2—Changes in quality;—

(1) Contrary aft. sens. 2 cold return; 2 coolish return.

3—Intensity. 6 faint, 2 distinct; 3 intense.

4—Localization. 8 diffuse; 3 distinctly localized.

5—Manner of appearance. 1 came quick; 10 slowly.

6—Manner of disappearance;—

(a) Primary. 1 quickly; 10 disappear gradually; 5 very persistent.

(b) Secondary. 4 died down suddenly; 7 fade more gradually.

### Subject II.

1—Quality. 2 pleasant warmth; 1 burning; 1 tingle; 1 smarting; 1 cold

2—Changes in quality. 1 primary sensation is neutral secondary burning.

(1) Contrary aft. sens. 1 warm stimulus gives cold after sensation.

3—Intensity. 4 strong, 2 stronger than stimulus.

4—Localization. 3 diffuse; 1 an area of ¼ of a circle; 2 dot-like area.

5—Manner of appearance. 2 quite suddenly; 4 more gradually.

6—Manner of disappearance;—

(a) Primary. 2 fairly sudden; 6 radiate off.

(b) Secondary. All hard to tell, mingle with heat of the skin.

### Subject III.

1—Quality. 3 no touch merely warmth; 3 much more definite warmth than radiation; 3 touch and heat

2—Changes in quality. 1 first pressure and heat then only heat.

3—Intensity. 3 moderately intense; 1 intense; 5 mild.

4—Localization. All somewhat spread, but still localizable in general way.

5—Manner of appearance. 7 return in rising and falling waves but not as rythmic as touch; 1 comes gradually; 1 more suddenly.

6—Manner of disappearance;—

(a) Primary. All go gradually.

(b) Secondary. All go gradually.

### Subject IV.

1—Quality. 3 pressure and smarting warmth; 3 warm; 3 smart; 1 perhaps cool.

2—Changes in quality. 1 pressure changes to smarting warmth; 1 warm changes to throbbing.

(1) Contrary aft. sens.; 1 after sensation is cold.

3—Intensity. 7 very distinct; 3 more diffuse.

4—Localization. 3 spread; 2 change position; 1 localized; 4 diffuse.

5—Manner of appearance. 4 come in streaks; 6 come slowly.

6—Manner of disappearance;—

(a) Primary. All fade gradually.

(b) Secondary. 3 die away in throbbing; 7 fade gradually.

### Subject V.

1—Quality. 2 pressure and heat; 3 warmth; 2 tingling; 1 cold.

2—Changes in quality. 1 first pressure then warm then cold.

(1) Contrary aft. sens. 1 returns cold, then warm, then slightly cool.

3—Intensity. 6 slight; 2 moderate.

4—Localization. 5 diffuse; 2 localized

5—Manner of appearance. 3 come quickly; 5 slower.

6—Manner of disappearance;—

(a) Primary. 3 go quickly, 5 persistent.

(b) Secondary. 1 gone very quickly; 6 gradually disappear; 1 spreads rapidly and disappears.

### Subject VI.

1—Quality. 4 warm; 1 hot

2—Changes in quality.

3—Intensity. 4 moderate; 1 intense

4—Localization. 2 localized; 3 diffuse.

5—Manner of appearance. 1 came suddenly; 2 in waves; 2 gradually.

6—Manner of disappearance;—

(a) Primary. All diffused away gradually.

(b) Secondary. 3 gradually; 2 more quickly.

## Stimulus. Punctiform Heat.

### Subject I.

1—Quality. 1 prickly; 1 the burning feeling of menthol; 1 burning; 3 distinct warmth.

2—Changes in quality. 1 prickly feeling of primary sensation changed to the burning feeling of menthol; 1 menthol feeling and then warmth.

3—Intensity. 4 mild; 2 strong.

4—Localization. 2 diffuse spreading; 2 feels like an area; 2 well localized.

5—Manner of appearance. 2 suddenly; 4 gradually.

6—Manner of disappearance;—

(a) Primary. 2 gradually diffuse and shade off into menthol feeling; 3 gone quickly; 2 fade gradually.

(b) Secondary. 5 gradually; 1 gone very quickly.

### Subject II.

1—Quality. 4 faint warmth; 2 clear warmth; 1 tingle.

2—Changes in quality.

3—Intensity. 2 moderately strong; 5 faint.

4—Localization. 2 punctiform and well localized; 1 an area of 2 mm.; 4 diffuse, and spreading.

5—Manner of appearance. 1 gradually; 2 more sudden; 1 moderately abrupt.

6—Manner of disappearance;—

(a) Primary. Seem to go out rather suddenly but very hard to tell.

(b) Secondary. Seem to go out rather suddenly, but very hard to tell.

### Subject III.

1—Quality. 2 nearly pain-warmth; 1 sort of large diffuse pain.

2—Changes in quality.

3—Intensity. 2 intense; 1 moderate.

4—Localization. 1 heat and touch combined, touch is a definite spot but heat is a large diffuse area; 1 exactly located; 1 diffuse.

5—Manner of appearance. 2 "well up"; 1 comes more gradually.

6—Manner of disappearance;—

(a) Primary. 2 gradual, 1 goes more suddenly.

(b) Secondary. 3 go rather quickly.

### Subject IV.

1—Quality. 3 clear heat; 3 almost a burn; 2 faint warmth.

2—Changes in Quality.

3—Intensity. 2 faint; 1 strong as stimulus; 3 strong; 2 *very* intense.

4—Localization. 4 punctiform cold; 2 spread to area previously stimulated; 1 runs in deeper; 1 areal.

5—Manner of appearance. 5 came quickly; 3 came more slowly.

6—Manner of disappearance;—

(a) Primary. 4 rather suddenly; 5 more slowly.

(b) Secondary. 4 disappear more, and 4 less quickly.

### Subject V.

1—Quality. 1 painfully warm; 2 warm prickling sensation; 4 warm pressure.

2—Changes in quality. 1 pain, then large warm prickle.

3—Intensity. 2 painfully warm; 4 moderate; 1 mild.

4—Localization. 1 spot ¾ in. in diameter; 1 spot 1½ in.; 2 localized as a point; 3 diffuse.

5—Manner of appearance. 5 slowly; 2 quickly.

6—Manner of disappearance;

(a) Primary. 5 quickly; 4 gradually

(b) Secondary. 4 very persistent; 3 fade slowly.

### Subject VI.

1—Quality. 2 quite warm; 2 painfully warm.

2—Changes in quality;—

(1) Contrast. 1 area around the spot becomes cool.

3—Intensity. 2 quite intense; 2 moderate

4—Localization. 1 seems an area of 3 mm.; 2 whole area becomes warm but stimulus persists on the spot more vividly; 1 doesn't seem to be on the surface, seems to go down deeper.

5—Manner of appearance. 4 come slowly.

6—Manner of disappearance;—

(a) Primary. all go gradually.

(b) Secondary. 1 spreads; 2 radiate off; 1 goes gradually.

## "Electric Heat."

### Subject I.

1—Quality. 1 smarting, biting irritation.

2—Changes in quality

3—Intensity. 1 quite strong

4—Localization. 1 felt areal.

5—Manner of appearance. 1 comes suddenly.

6—Manner of disappearance;—

(a) Primary. Quite persistent.

(b) Secondary. 1 persists.

### Subject II.

1—Quality. 1 hot; 1 warmth; 1 cold.

2—Changes in quality;—

(1) Contrary aft. sens. 1 returns cold.

3—Intensity. 1 intense; 1 quite strong, 1 mild.

4—Localization. 2 not localized; 1 localized

5—Manner of appearance. 2 suddenly, 1 gradually

6—Manner of disappearance;—

(a) Primary. 2 quickly, 4 go more slowly

(b) Secondary. 2 seem to disappear quickly, 1 more gradual.

### Subject IV.

1—Quality. 2 warm; 3 sort of burn.

2—Changes in quality.

3—Intensity. 2 moderate; 1 strong; 2 very intense.

4—Localization. 2 localized; 1 whole arm feels warm; 1 heat radiates from the spot; 1 spreads.

5—Manner of appearance. 2 suddenly; 3 more slowly.

6—Manner of disappearance;—

(a) Primary. 4 fade out; 2 go suddenly.

(b) 5 spread and radiate off.

## Stimulus. Radiant Cold.

### Subject I.

1—Quality. 3 clear cold, 10 mild diffuse cold.

2—Changes in quality.

3—Intensity. 6 faint, 5 moderate; 2 strong.

4—Localization. 4 diffuse; 9 more diffuse than contact cold.

5—Manner of appearance. 13 markedly recurrent, come in waves.

6—Manner of disappearance;—

(a) Primary. 17 fade away gradually.

(b) Secondary. 13 wave-like decrease.

### Subject II.

1—Quality. 1 cold, 1 cool.

2—Changes in quality.

3—Intensity. 1 faint, 1 quite cold.

4—Localization. 2 diffuse.

5—Manner of appearance. 2 gradually.

6—Manner of disappearance;—

(a) Primary. 3 fade out, 1 goes more quickly.

(b) Secondary. 2 fade gradually.

### Subject III.

1—Quality. 5 cool waves, not as distinct as pressure.

2—Changes in quality,—

(1) Contrast. 1 the stimulus felt as hot, and space around it cool.

3—Intensity. 4 faint, 1 definite.

4—Localization. None of them well localized.

5—Manner of appearance. 5 in waves.

6—Manner of disappearance;—

(a) Primary. Impossible to tell.

(b) Secondary. Impossible to tell.

### Subject IV.

1—Quality. 2 rheumatic pain.

2—Changes in quality.

3—Intensity. 2 slight.

4—Localization. 1 localized; 1 spreads to elbow joint.

5—Manner of appearance. 2 gradual.

6—Manner of disappearance;—

(a) Primary. 2 gone very quickly; 1 wave, persistent, 1 gradual.

(b) Secondary. 2 impossible to tell.

### Subject V.

1—Quality. 1 slightly cool; 1 warm.

2—Changes in quality;—

(1) Contrary aft. sens. 1 cool, returns warm.

3—Intensity. 2 faint

4—Localization. 1 a cool breeze coming to a point from all directions; 1 diffuse warmth.

5—Manner of appearance. 1 (see "Localization"); 1 gradual.

6—Manner of disappearance;—

(a) Primary. All disappear quite quickly but gradually.

(b) Secondary. Both disappear quite quickly but gradually.

### Subject VI.

1—Quality. No secondary sensations, primary were faint waves of warmth that disappeared gradually.

## Stimulus. Areal Cold.

### Subject I.

1—Quality. 3 tickling; 4 vividly cold; 1 moist feeling, no pressure; 3 so cold as to be almost painful; 1 feels like a cool vapor under the skin.

2—Changes in quality. 2 in the first returns there is contact but all the others are pure cold.

3—Intensity. 2 intense; 2 more intense than stimulus; 8 *very* intense.

4—Localization. 5 diffuse; 7 clearly located spots.

5—Manner of appearance. 7 quickly; 5 in more gradual waves.

6—Manner of disappearance;—

(a) Primary. 15 slowly, i. e. gradually.

(b) Secondary. 12 persistent, i. e. very gradual.

### Subject II.

1—Quality. 7 vivid cold, identical with stimulus; 5 cold and contact.

2—Changes in quality.

3—Intensity. 9 vivid cold, 3 stronger than stimulus.

4—Localization. 1 goes down like a cone with its base on the skin; 4 spiral instead of sinking in; 2 more punctiform.

5—Manner of appearance. 5 came quickly; 7 more slowly.

6—Manner of disappearance;—

(a) Primary. All very persistent, fading gradually

(b) Secondary. All very persistent, fading gradually.

### Subject III.

1—Quality. 3 cool; 6 definite cold, without touch; 1 cold and touch.

2—Changes in quality.

3—Intensity. 3 slight; 7 clear distinct cold.

4—Localization. 7 localized clearly, 3 more diffuse.

5—Manner of appearance. 6 come quickly; 4 slowly.

6—Manner of disappearance;—

(a) Primary. All fade out.

(b) Secondary. All fade out, in an indefinite feeling.

### Subject IV.

1—Quality. 2 tingling and throbbing with some pressure; 3 burning cold; 1 tingling

2—Changes in quality. 1 cold and tactual, tactual goes and cold remains; 1 stimulus is pressure and cold, no pressure in aft. sens.; 1 return may be either hot or cold.

3—Intensity. 4 intense cold; 1 cool tingling; 1 mild.

4—Localization. 2 well localized; 2 spread out in the surface; 1 seems to move; 1 spreads following an artery.

5—Manner of appearance. 4 gradual; 2 more sudden.

6—Manner of disappearance;—

(a) Primary. 1 dies out quickly; the rest fade slowly.

(b) Secondary. 4 diffuse away; 1 gradual; 1 sudden.

### Subject V.

1—Quality. 5 cold; 4 cold and wet; 1 wet and heavy; 5 cold and pressure.

2—Changes in quality. 1 not cold in stimulus, after sensation decidedly so; 1 stimulus gave only touch, in aft. sens there was localized cold; 1 in primary aft. sens. there was contact and cold, in secondary only cold; 1 three recurrences, first pressure, second cold, third pressure.

3—Intensity. 13 clear and intense; 2 less distinct.

4—Localization. 4 localized; 2 not as localized as pressure; 1 not as deep as pressure but plainly not on the skin; 16 spread; 1 touch returned as a spot and cold radiated from it; 1 shot down toward fingers.

5—Manner of appearance. 3 come from below; 2 primary sensations spread and come to a head at the stimulated point; 2 waves; 3 come suddenly; 5 come gradually.

6—Manner of disappearance;—

(a) Primary. 5 spread away; 7 fade gradually; 5 persistent.

(b) Secondary. 5 persistent; 6 spread; 4 go quickly.

### Subject VI.

1—Quality. 6 cold; 5 exactly like another stimulus; 1 warm; 1 cold and contact.

2—Changes in quality;—

(1) Contrary aft. sens. 1 aft. sen. feels warm.

3—Intensity. 5 strong as stimulus; 5 clear; 3 moderate.

4—Localization. 12 well localized; 1 diffuse.

5—Manner of appearance. 10 come in gradually; 3 more sudden.

6—Manner of disappearance;—

(a) Primary. All very persistent, gradually diffusing.

(b) Secondary. All very persistent, gradually diffusing.

## Stimulus. Punctiform Cold.

### Subject I.

1—Quality. 2 stinging; 5 cold

2—Changes in quality

3—Intensity. 5 faint, 2 strong.

4—Localization. 1 seemed like a 1 in area, 4 well localized as points, but localized too low; 2 diffuse

5—Manner of appearance. 3 slowly, 4 quite quickly.

6—Manner of disappearance;—

(a) Primary. 5 very gradually, 2 can't be sure.

(b) Secondary. All fairly persistent

### Subject II.

1—Quality. 2 tingle; 1 faint pain, rheumatic, 1 cold tingle; 2 cold, 1 *very* cold.

2—Changes in quality. 1 cold tingle changes to pure cold

3—Intensity. 1 faint; 4 distinct, strong, 2 *very* intense

4—Localization. 2 punctiform; 5 unlocalized, diffuse.

5—Manner of appearance. 4 gradually, 3 suddenly.

6—Manner of disappearance;—

(a) Primary. 4 fade gradually, 3 gone more quickly

(b) Secondary. All fade rather slowly

### Subject III.

1—Quality. 4 cold; 3 cold and touch.

2—Changes in quality.

3—Intensity. 1 not intense; 1 mild; 2 distinct, 1 very strong, 2 as strong as stimulus

4—Localization. 4 localized; 2 stay localized longer than heat; 1 spreads.

5—Manner of appearance. 2 come in waves, or pulses, 2 seem to pulsate with the breathing, increasing with inspiration; 3 come gradually.

6—Manner of disappearance;—

(a) Primary. Fade gradually in all cases

(b) Secondary. 3 fade out; 4 go quickly

### Subject IV.

1—Quality. 8 decidedly cold; 1 tingling

2—Changes in quality.

3—Intensity. 5 intense; 3 quite strong, 1 mild.

4—Localization. 6 punctiform, localized, 1 diffuse, 1 spreads; 1 whole arm becomes cold.

5—Manner of appearance. 4 return gradually, last return the slowest; 3 more quickly; 2 can't say.

6—Manner of disappearance;—

(a) Primary. 9 fade away.

(b) Secondary. All fairly persistent.

### Subject V.

1—Quality. 4 cold; 1 little prickly feeling like pressure; 3 cold and wet; 1 cold pressure, 1 cool wave over the place, 1 an itching pain with a little cold in it

2—Changes in quality.

3—Intensity. 5 slight, 6 clear and intense.

4—Localization. 2 areal feeling, 2 diffuse; 2 well localized; 3 pointed; 1 areal feeling seems to come to a point, 1 spreads

5—Manner of appearance. 2 return in throbs; 4 come quickly, 2 areal sensations come to a head, 3 waves.

6—Manner of disappearance;—

(a) Primary. 13 very persistent, go gradually; 3 go more suddenly.

(b) Secondary. 5 spread away; 6 persistent, fading gradually.

### Subject VI.

1—Quality. 4 dull cold; 1 burning cold.

2—Changes in quality.

3—Intensity. 4 strong; 1 *very* intense.

4—Localization. 2 go in deep; 1 broadened into two points; 2 well localized.

5—Manner of appearance. 1 returns in long waves close to the limen; 1 increased by throbs; 2 suddenly; 1 waves.

6—Manner of disappearance;—

(a) Primary. 6 spread, 2 gone quickly

(b) Secondary. 4 persist steadily, gradually diminishing; 1 goes in deep and disappears.

## Stimulus. "Electric Cold."

### Subject I.

1—Quality. 1 cold.

2—Changes in quality. 1 primary sensation changes to smarting.

3—Intensity. 1 mild.

4—Localization. 1 uncertain

5—Manner of appearance. 1 gradual.

6—Manner of disappearance;—

(a) Primary. 2 gradually

(b) Secondary. 1 gone quickly.

### Subject II.

1—Quality. 2 cold; 1 cool tingle.

2—Changes in quality.

3—Intensity. 1 mild; 1 moderate.

4—Localization. 2 diffuse.

5—Manner of appearance. 2 gradually.

6—Manner of disappearance;—

(a) Primary. 3 gone rather quickly; 1 quite persistent.

(b) Secondary. 2 fade rapidly.

### Subject III.

1—Quality. 4 clear definite cold; 1 pricking pain.

2—Changes in quality. 2 a persistent cold, then a pulse of pain comes in.

3—Intensity. 5 very distinct.

4—Localization. 4 sharply localized; 1 more diffuse.

5—Manner of appearance. 5 suddenly.

6—Manner of disappearance;—

(a) Primary. 3 persist; 4 go more quickly.

(b) Secondary. None very persistent

### Subject IV.

1—Quality. 2 cold; 1 very cold.

2—Changes in quality;—

(1) Contrary aft. sens. 1 cold changes to warm, to cold, to warm.

3—Intensity. 1 intense; 2 moderate.

4—Localization. 2 well localized; 1 cold radiating from the spot.

5—Manner of appearance. 2 come slowly; 1 more suddenly.

6—Manner of disappearance;—

(a) Primary. 3 gradually.

(b) Secondary. 3 go gradually.

## Stimulus. Punctiform Pain.

### Subject I.

1—Quality. 1 pure pain; 3 clear pain; 2 pain with pressure; 1 faint pain.

2—Changes in quality. 1 pain and pressure changes to pressure alone, then to pain alone; 1 painful but dies instantly into contact.

3—Intensity. 6 faint; 1 strong.

4—Localization. 4 localized; 3 diffuse.

5—Manner of appearance. 4 slowly, i. e. gradually; 1 uncertain; 2 quite sudden.

6—Manner of disappearance;—

(a) Primary. 7 quickly; 2 slowly.

(b) Secondary. 4 quickly; 1 persistent; 2 uncertain.

### Subject II.

1—Quality. 2 sharp contact rather than pain; 4 sharp pain; 2 sharp pain and pressure.

2—Changes in quality. 1 pain changes to pressure; 1 first return is sharp pain, second is pressure; 1 first return is sharp pressure then sharp pain; 1 primary after-sensation sharp pain and pressure, secondary pain; 1 sharp pain, returns pressure with sharp pain.

3—Intensity. 3 strong as stimulus; 4 intense pain; 1 quite strong.

4—Localization. 1 rather diffuse; 7 well localized.

5—Manner of appearance. 3 come back slowly; 5 quickly.

6—Manner of disappearance;—

(a) Primary. 2 die out quickly; 6 fade gradually.

(b) Secondary. 1 gone quickly; 7 quite persistent.

### Subject III.

1—Quality. 2 sharp beating; 6 sharp distinct pain.

2—Changes in quality. 2 pain settles into an ache; 3 touch and pain sensations alternate; 1 stimulus only sting, distinct pain in after sensation.

3—Intensity. 3 strong; 2 steady; 3 faint.

4—Localization. 5 localized; 2 spread; 1 seems an area of 1.5 cm.

5—Manner of appearance. 1 comes in quick beats, first two quick, the third slow; 5 come quickly; 2 come slowly.

6—Manner of disappearance;—

(a) Primary. 2 gradually; 8 gone more quickly.

(b) Secondary. 1 diffuses slowly; 7 gone quite soon.

### Subject IV.

1—Quality. 1 stabbing pain; 4 prickly and throbbing; 2 general ache.

2—Changes in quality. 1 pain and pressure together, pain fluctuates but pressure is constant; 1 throbbing and pressure alternate; 1 ache with periods of prickling.

3—Intensity. 3 quite intense; 3 sharp; 1 less intense.

4—Localization. 5 localized; 2 diffuse.

5—Manner of appearance. 3 in irregular short jabs; 2 throb with the pulse; 2 come gradually.

6—Manner of disappearance;—

(a) Primary. 4 go rather quickly; 5 persist.

(b) Secondary. 5 go quickly; 2 more slowly.

### Subject V.

1—Quality. 2 pressure; 1 pressure with a queer tingle; 1 sharp pain; 1 pressure and ache.

2—Changes in quality. 2 pressure returns, then pressure with a tingle.

3—Intensity. 1 quite strong; 2 faint; 2 moderate.

4—Localization. 3 diffuse; 1 well localized; 1 localized.

5—Manner of appearance. 5 gradual.

6—Manner of disappearance;—

(a) Primary. 4 gone quickly; 2 gradually

(b) Secondary. 1 disappears more slowly; 3 gradual; 1 gone quickly

### Subject VI.

1—Quality. 7 sharp pain; 3 ache.

2—Changes in quality. 1 stimulus is coldish, after-sensation is only pain; 1 second return is an ache.

3—Intensity. 3 faint; 6 strong; 1 moderate.

4—Localization. 6 pointed; 4 diffuse.

5—Manner of appearance. 7 come quickly; 3 more slowly

6—Manner of disappearance;—

(a) Primary. 2 go quickly; 8 gradually, dying down.

(b) Secondary. 4 turned into an ache; 3 went quickly; 2 left a soreness; 1 goes gradually.

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# On the Relation of the Methods
OF
# Just Perceptible Differences and Constant Stimuli

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# I. INTRODUCTION

Psychophysics has evolved a number of procedures by means of which the sensitivity of a subject can be determined. These procedures differ widely as to the experimental arrangement which they require and as to the calculation to which the results are subjected, but they have the common purpose of measuring the sensitivity of the subject. We may say, in general, that a psychophysical method is a prescription for the collecting of data and their evaluation in such a way that the result enables us to compare the sensitivity of different subjects, or of the same subject under different conditions or at different times. All these methods agree in this one point, that by them we undertake to give measures of sensitivity. The quantities which are used as the measures of sensitivity are widely different and, perhaps, not always directly comparable. One is confronted with the situation that the comparison of the sensitivity of different subjects by a given method yields perfectly satisfactory results, but that these results do not always agree with those obtained by other methods. One is then led to ask, what the relation of these different measures of sensitivity may be. This problem is frequently stated in the form of the question of the relation of the method of constant stimuli and the method of just perceptible differences.

It has been frequently pointed out that the methods of constant stimuli and just perceptible differences show variations of an experimental or of a mathematical nature in consequence of which their results are not comparable. Numerous investigators have noted this fact and have made different classifications of the methods on the basis of differences in their experimental procedure or in the treatment of the results. In all of these classifications the method of just perceptible differences is always the representative of one group and the method of constant stimuli is given as an example of another group [cf. Titchener, *Experimental Psych.,* II, II, pp. 315-318]. At present these two methods have been developed to a more or less standard form, evidenced by the fact that different authors describe them almost uniformly. The method of just perceptible differences is described by Wundt [*Phys. Psych.,* 5th Ed., vol. I, pp. 470]; G. E. Müller [*Die Gesichtspunkte und die Tatsachen der Psychophysischen Methodik,* pp. 179] and Titchener [*Experimental Psychology,* vol. II, part I, pp. 55-69; part II, pp. 99-143]. A description of the method of constant stimuli is to be found in G. E. Müller [*Gesichtspunkte,* pp. 35] and in Titchener [*Exp. Psych.,* II, part I, pp. 92-118; part II, pp. 248-318].

The solution of the problem of the relation of the psychophysical methods certainly would have been much simpler, had it been possible to subject the same experimental data to the different calculations. The results of experiments made according to these descriptions cannot be treated as material for both methods. It was therefore necessary to divide the experiments into two groups, in one of which the data was taken by the method of just perceptible differences and in the other by the method of constant stimuli; and this brought with it the difficulty of deciding whether a given difference between the results was due to chance variations; to changes in the attitude of the subject, or to differences in the methods themselves. The differences in the arrangement of the experiments by the two methods, indeed, are so great that one may suspect the existence of differences in the attitude of the subject.

It has been argued that the influence of expectation, found in the method of just perceptible differences, where the subject has a knowledge of the stimuli, is a serious handicap. This influence is obviously absent in the method of constant stimuli since the experiments are arranged in such a way that the subject is given no clue whatsoever, as to the objective relation of the stimuli.

In any study of the relation of these two methods, an effort must be made to eliminate all such influences and to have the data in such form that any variations between the results will be due to differences in the methods themselves and not to any of the influences due to the experimental procedure. One means of eliminating the influence of expectation is to mingle the experiments by the two methods in such a way that the subject has no information as to the stimuli compared. The conditions in the two groups of experiments will be very nearly identical, if the results are taken simultaneously, but these conditions may undergo certain changes in the course of the experimentation. This belief cannot be disposed of offhand since the collection of the data necessarily requires a considerable time. One of the most important of these conditions is the psychophysical make-up of the subject. It is very likely that the psychophysical make-up itself does not remain constant since at least one factor, namely practice, changes. The difficulty, therefore, is twofold and requires an investigation of the changes due to variations that have an experimental basis, and also an investigation of the purely formal character of the methods. These two sides of the problem must not be confused. It may well be that the two methods are formally identical but in actual experimentation do not give the same results, since they are performed under different conditions. The suspicion that the conditions are not the same for the methods of just perceptible differences and constant stimuli is very strong, since the entire experimental arrangement is such as to produce different attitudes on the part of the subject. Thus it cannot be expected that the two methods will give the same results unless the experiment is arranged in such a way as to make the conditions directly comparable. Many experimenters have noted the fact that if results were taken by one of these methods and compared with the results of the other, that they do not agree. We may mention Meinong [*Ueber die Bedeutung dest Weberschen Gesetzes. Zeits. f. Psych. und Phys. der Sinnesorgane,* XI, 1896, pp. 244]; Ebbinghaus [*Psych.,* I, pp. 504]; Merkel [*Phil. Studien,* IV, p. 543] and Boas [*Pflüger's Arch.,* XXVIII, 1882, pp. 562].

The investigation of the formal character of the methods is the problem which Urban set for himself, and he devised for this purpose the notion of the probability of a judgment, which logically led to the notion of the psychometric functions. [*The Application of Statistical Methods to the Problems of Psycho-Physics,* 1908, pp. 106.] Forming a judgment on the comparison of two stimuli is a chance event and there exists a certain probability with which a certain judgment will occur under certain conditions. If our experimental data are extended enough, the observed relative frequency of that judgment may be regarded as an empirical determination of its unknown probability. One of the conditions of a judgment is obviously the intensity of the stimuli. The psychometric functions give the probabilities of the different judgments as functions of the intensities of the comparison stimulus. Urban showed that the method of just perceptible differences could be analysed by means of these notions and that its final results could be stated in terms of the probabilities of the different judgments and the intensities of the stimuli. Empirical determinations of the probabilities of the extreme judgments, i. e. of the judgment greater and smaller, are the basis for the calculation by the method of constant stimuli, and it is therefore possible to test the formal character of the methods under discussion on one and the same set of results. Experience showed that both methods of treatment gave essentially the same results.

We are, therefore, confronted with the fact that the methods of constant stimuli and just perceptible differences give the same results if the calculations are made on the same material; but different results if the materials are different. From this we conclude that the methods are formally identical but that the conditions, under which the experimental data must be gained, are materially different; that is, that the methods favor different attitudes of the subject. One must, therefore, devise an experimental procedure by which the two methods can be performed under as nearly identical conditions as possible, in order to study the agreement of the results from the two methods.

The collection of a large amount of material enables one to study incidentally, an entirely different problem; that of whether the conditions remain approximately the same throughout the experiment, or if they undergo certain changes. If the physical conditions of an experiment are kept as constant as possible, so that no variations in the conditions can be attributed to them, we must attribute any varying conditions to a change in the psychophysical make-up of the subject. One factor, at least, making such a change extremely probable is the one due to the practice acquired by the subject during the performance of the experiments.

Extended material, therefore, enables one to study the influence of progressive practice. If the experiments are made on two subjects, one of whom has a high degree of training in this kind of experimentation, while the other has none, one has the opportunity to study the influence of practice in a very advanced stage and to compare it with the practice in the initial stage.

These factors have led to the selection of the experimental arrangement for this study. It enables us to investigate the problems of the formal and experimental relations of the methods of just perceptible differences and constant stimuli, and incidentally, the effect of progressive practice.

My thanks are due to Prof. F. M. Urban for suggesting this problem to me and for acting as a subject. I also have to thank Prof. E. B. Twitmyer for revision of manuscript.

## II. ARRANGEMENT OF EXPERIMENTS

This paper is based on the results of experiments in lifted weights on two subjects. The experimentation began January 3, 1912, and was completed February 20, 1912. During this time records were taken almost every day and many times during the morning and afternoon. Subject I, Dr. F. M. Urban, was highly trained in the technique of lifted weights and was the same as the one designated as subject II in a former study by Urban [Statistical Methods]. Subject II, the writer, had some experience in psychological experimentation but, at the beginning of this experiment, had no training in judging small differences of lifted weights. He was given one day's practice, in order to become acquainted with the experimental procedure and with the sensations produced by weights that differ but slightly in intensity. From the second day his judgments were recorded.

The weights used in this experiment were hollow brass cylinders, closed at one end. They were approximately 2.5 inches in diameter and 1 inch high and the wall was 0.0625 inches thick; and they were brought to any desired weight by filling them with shot and parafine. Although these weights had the same outward appearance to the subject, each weight could be recognized by the experimenter by means of small numbers stamped on them with a steel die. The set consisted of 15 weights; of which 7 were standard weights of 100 grams each. The comparison weights for the set used with the method of constant stimuli were 84, 88, 92, 96, 104 and 108 grams. There were also two weights of 84 grams and 97.44 grams which served for the preparation of the variable stimulus in the method of just perceptible differences.

These cylinders had been made slightly lighter than the weight desired and a very delicate adjustment could be obtained by inserting shot and parafine until they were heavier than the proper intensity. The parafine was then carefully scraped out until the desired weight was obtained. An effort was made to use as little parafine as possible since it is susceptible to greater variation from

| Number of Weight | Desired Weight | 1/2/12 | 1/8/12 | 1/15/12 | 1/22/12 | 1/29/12 | 2/5/12 | 2/12/12 | 2/22/12 |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 100.000 | +10 | 0 | + 5 | 0 | 0 | — 5 | —10 | —10 |
| 2 | 100.000 | + 5 | + 5 | +10 | + 5 | + 5 | + 5 | + 5 | 0 |
| 3 | 100.000 | + 5 | 0 | 0 | — 5 | 0 | —10 | —10 | —10 |
| 4 | 100.000 | — 5 | —10 | —10 | —10 | —10 | —15* | 0 | — 5 |
| 5 | 100.000 | 0 | — 5 | — 5 | — 5 | — 5 | —10 | —10 | —10 |
| 6 | 100.000 | 0 | — 5 | 0 | — 5 | — 5 | —10 | —10 | —15 |
| 7 | 100.000 | 0 | — 5 | — 5 | —10 | —10 | —15* | — 5 | — 5 |
| 9 | 97.440 | 0 | 0 | — 5 | —10 | —10 | —15* | 0 | 0 |
| 52 | 84.000 | — 5 | — 5 | —10 | —15* | 0 | 0 | — 5 | —10 |
| Blank | 88.000 | 0 | — 5 | — 5 | —10 | —10 | —10 | —15* | 0 |
| 12 | 92.000 | + 5 | — 5 | —10 | —15* | 0 | — 5 | —10 | —10 |
| 13 | 96.000 | 0 | —10 | —10 | —15* | 0 | 0 | 0 | 0 |
| 14 | 104.000 | —10 | —15* | 0 | — 5 | 0 | 0 | —10 | —10 |
| 15 | 108.000 | — 5 | —10 | —10 | —15* | 0 | —10 | —10 | —10 |
| 19 | 84.000 | + 5 | 0 | 0 | 0 | 0 | — 5 | — 5 | —10 |

TABLE I

atmospheric changes than the shot. It was not deemed necessary to determine the weights within a smaller value that 5 mgr. The weights were tested daily for the first week and then once a week throughout the experiment. Whenever a weight was found to vary more than 10 mgr., it was readjusted, but this was necessary only nine times during the experiment. During the first three weeks only one adjustment was necessary and no single weight had to be adjusted more than once. Table I contains the weights of the cylinders and also the amount of variation discovered in them, these variations being given in + or — mgr. from the correct weight. The first column contains the numbers stamped on the cylinders; the next column gives the correct weight of each, and the succeeding columns contain the variations of the cylinders found on the date at the head of the column. A star indicates that a cylinder was found to vary more than 10 mgr. and that it was readjusted.

In the choice of the materials which compose the weight, there are three essential points to be considered. In the first place, the weight must show very little variation from atmospheric changes; secondly, there must be no distinguishing marks on them by means of which the subject can tell one from another. And thirdly, they must be the same in temperature and must arouse the same tactile sensations. Various types of weights have been suggested in the past. The weights used by Fullerton and Cattell were wooden boxes weighted to the proper intensity with shot and raw cotton. They were 6 cms. in diameter and 3 cms. high [Fullerton and Cattell, *The Perception of Small Differences,* 1892, pp. 118]. Jastrow [*Amer. Journal of Psych.,* V, p. 245] used weights of the same type. Galton [*Inquiries into Human Faculty,* 1883, p. 373] used weights that were made by placing shot in a cartridge shell. Urban [*Stat. Meth.,* p. 1] used the same brass cylinders that were employed in the present study. Brown [*The Judgment of Difference, Univ. of California Pub.,* V, I, No. 1, 1910] used cylindrical tin boxes 2.5 cms. high and 4.5 cms. in diameter, which were weighted with shot and parafine.

In the choice of weights for our experiment, the wooden boxes must be at once thrown out of consideration, since they do not fulfil the first of our requirements. The variations in these weights are quite considerable as was shown by Urban [*Stat. Meth.*, p. 173]. In this study Urban gives a table showing the variations in his set of weights, which were similar to those used in this experiment and a set of Cattell weights that were adjusted but not used. The cartridge weights are open to the same criticism, although probably not to as high a degree as the wooden weights. An effort should be made to have the weights consist of as anhygroscopic materials as possible. With the weights used in this experiment, the brass cylinders themselves and the shot are practically anhygroscopic. The parafine was included to keep the shot stationary and to simplify the adjustment and readjustment of the weights.

The weights were as nearly alike as it was possible to turn them out, making it impossible for the subject to distinguish between them. The table that follows contains the height and diameter of each weight to 0.001 of an inch, and it can be seen that these differences can be disregarded. Numbers were stamped on them so that they could be identified by the experimenter. The surfaces were polished and lacquered, rendering them similar to the touch. The weights were kept under exactly the same conditions and furthermore, they were handled the same number of times, so that there was no perceptible difference in temperature. Thus the cylinders used in this experiment seem to conform to all the requirements of a set of weights and furthermore, have the advantage of being easily adjustable.

| Weight | Height in inches | Diameter in inches |
|---|---|---|
| 1 | 0.996 | 2.466 |
| 2 | 0.998 | 2.468 |
| 3 | 0.998 | 2.470 |
| 4 | 0.995 | 2.470 |
| 5 | 0.997 | 2.468 |
| 6 | 0.997 | 2.464 |
| 7 | 0.998 | 2.464 |
| 9 | 0.990 | 2.468 |
| 12 | 0.997 | 2.468 |
| 13 | 0.999 | 2.469 |
| 14 | 0.998 | 2.467 |
| 15 | 0.997 | 2.468 |
| 19 | 0.996 | 2.467 |
| 52 | 0.997 | 2.466 |
| Blank | 0.996 | 2.468 |

The weights were placed at regular intervals around the circumference of a circular table with a revolving top, which was 75.5 cms. in diameter and was raised 68.0 cms. from the floor. The top was covered with a layer of prepared cork, which deadened the sound of the weights when replaced on the table. The position of each weight was indicated by a small number on the table. The standard and comparison weights were placed alternately—the standard weights at the odd, and the comparison weights at the even numbers on the table.

The subject was seated in a comfortable position with his right arm supported by a table in such a way that the hand, from the wrist down, hung over the edge. An effort was made to have the edge of the supporting table strike approximately the same position of the forearm of the subject. The turn top table was then brought into such a position that, with merely a downward movement of the wrist, the hand would grasp one of the weights.

The cylinders were lifted with the right hand; most of the weight being sustained by the thumb, second and third fingers, and the first and little fingers resting on the edge. The movements of the hand were regulated by the beats of a metronome, which was adjusted to 92 beats per minute, while every fourth beat was accentuated by the automatic stroke of a bell. These hand movements were regulated in the following manner. At the start of each trial, the hand of the subject was raised at the wrist, with the forearm remaining on the table. At the stroke of the bell, the hand was dropped and the weight, which had been brought directly underneath by turning the table, was grasped. At the second stroke of the metronome the weight was lifted, and at the next stroke, it was replaced on the table. Finally at the fourth stroke, the empty hand was lifted, returning to its original position. Between the third stroke of the metronome and the bell following, the experimenter turned the table so that the next weight to be lifted, was directly under the hand of the subject, and everything was ready for the next lifting. In a very short time these wrist movements became quite automatic. The weights were lifted from 2 to 4 cms. and an effort was made to have the height of lifting constant for each subject. Due to the control of the metronome, each weight was in the air approximately the same length of time.

A screen was placed between the subject and the table so that it was impossible for the subject to see the weights; his hand passing through a slit in this screen. Furthermore both subjects voluntarily closed their eyes while making judgments, as they believed that they could make their judgments with more accuracy in that way.

Previous investigators have not made a very clear analysis of the space error. They have sought to avoid it or eliminate its influence rather than explain it. The obvious method of eliminating the space error and the one that has been most frequently used, is to perform the experiment twice, in both of the spatial relations; that is, with the standard weight to the left and right of the comparison weight. Then the error of the one spatial relation counterbalances the error of the other, which is in the opposite direction. In the present study the space error was avoided in a simpler manner; since by means of the revolving top of the table, all side movements of the hand were eliminated. The table was turned so that the weight to be lifted was brought directly under the hand of the subject. Thus the only movements necessary were in one direction merely—directly downward. Care was taken that the subject did not reach to one side or the other in grasping a weight, since in this case a space error would have occurred. An effort has been made before to avoid the space error by experimental technique rather than eliminate it by repeating the experiment in the two spatial relation. [L. Steffens, *Zeitschrift f. Psych. und Physiol. der Sinnesorgane,* XXIII, 1900, pp. 279, and J. Fröbes, *Zeit. f. Psych. und Physiol. der Sinnesorgane,* XXXVI, 1904, pp. 234]. In these studies the weights were placed on a board which was pushed along under the hand of the subject, so that the weights in turn were directly underneath. This procedure, although it eliminated the space error, had the disadvantage that when a series had been taken, the board had to be replaced in its original position before a second series could be begun. With our experimental arrangement, however, any number of series could be run off in succession. Besides this, the table, which revolves very easily, can be moved with greater regularity and accuracy than could ever hoped to be obtained with a sliding board.

The time error was present in our experiments and no effort was made to either avoid or eliminate it. The standard stimulus was always lifted first and the comparison stimulus second. The metronome controlled all hand movements and kept them regular so that the time error was constant throughout the experiment. As the investigation of the sensitivity of the subjects was not of primary interest, and as a constant time error should not effect the relationship of the results obtained by the two methods under discussion, no attempt was made to avoid this error.

The comparison weights were placed about the table in a carefully arranged order. This order was changed four times during the experiment, partly to eliminate the influence of the particular arrangements, partly to counteract the influence of the knowledge about the arrangement used, which the subjects might have acquired. Table II gives these orders. The first column gives the table numbers in pairs: 1 being the first standard stimulus, 2 the first comparison stimulus, 3 the second standard stimulus and so forth. The other columns give the comparison weights at the even numbers of that pair. The C indicates the comparison weight of the method of just perceptible differences series. Each column is under the date at which the order was adopted. In every order, no matter how carefully planned, there

| Table No. | 1/3/12 | 1/10/12 | 1/22/12 | 2/18/12 |
|---|---|---|---|---|
| 1 and 2 | 96 | 84 | 84 | 88 |
| 3 and 4 | 104 | 104 | 104 | C |
| 5 and 6 | 108 | 96 | C | 104 |
| 7 and 8 | 84 | C | 88 | 96 |
| 9 and 10 | 92 | 92 | 92 | 84 |
| 11 and 12 | C | 108 | 108 | 92 |
| 13 and 14 | 88 | 88 | 96 | 108 |

TABLE II

are certain landmarks by means of which the subject can tell in what part of the series he is. Such a landmark is seen in the first series where the two heaviest weights (104 and 108 gms.) come together. Another occurs in the second order where the two lightest comparison weights [84 and 88 gms.] came together. Both subjects acted as experimenters and so necessarily became acquainted with the order in which the weights were presented. Furthermore, the experiments were conducted daily and so the subjects became acquainted with the orders more rapidly than if there had been a longer interval between experimentation.

One complete revolution of the table involved the passing of seven judgments: six on invariable comparison weights for the method of constant stimuli, and one on a variable comparison weight for the method of just perceptible differences.

This seventh comparison weight, indicated by C in table II, was adjusted for the method of just perceptible differences in the following manner. At each revolution of the table, a judgment was passed between it and a standard weight in the same manner as the other pairs. After a judgment had been taken on each of the seven pairs, steel bearings of a given number were placed in cylinder C and another complete revolution of the table was made. Then the same number of bearings were placed in cylinder C. This was continued until C weighed over 108 gms., the weight of the heaviest stimulus used in the method of constant stimuli. The bearings which weighed 0.42 gms., were of a surprising uniformity in weight. All the bearings were weighed and they did not show any variations within 5 mgr., which was the limit of exactitude in our weighing. We at first intended to use shot for the purpose of weighting our variable stimulus, but found that the differences among them were quite considerable. Cotton wool was placed in the bottom of the cylinder so that the total weight was 84.80 gms. The cotton wool was placed in the cylinder to keep the bearings from moving about and thus by the noise, indicating to the subject which cylinder he was lifting. The bearings made a noise only three or four times during the lifting, and each time the judgment was thrown out and another taken.

Ten series were taken by means of this method. In series II the variation was two bearings for each revolution of the table. For series III the variation was three bearings, and so on until series X, when a variation of ten bearings was used. In an effort to test the "carefully graded approach" of the central intensities of the comparison stimulus, which is considered by some psychologists to be the keynote of the method of just perceptible differences, another series was planned [Titchener, *Experimental Psychology,* II, II, p. 103]. In this series the two extreme variations were seven bearings; the next two variations toward the central values were six bearings; then in order five, four, three, two, and the five central values varied only one bearing. This is designated as series I. It was not deemed profitable to perform a series with the variation of only one bearing, as this would have necessitated 54 revolutions of the table to complete each series.

Ten determinations of each series were taken; of these five were ascending and five descending. In the ascending series the proper number of bearings were placed in the cylinder, after each revolution of the table; while in the descending series, the total number of bearings were placed in the cylinder at the start of the experiment and after each revolution of the table, the proper number were removed. It is obvious that these series varied in length; the series X required only seven revolutions of the table while series II required 29 revolutions. As a matter of technique, two weights were used for this comparison stimulus. The first with the cotton wool weighed 84.80 gms. and the second with the cotton wool, 98.24 gms. In an ascending series, the 84.80 gm. cylinder was first judged empty, then successive judgments were taken until it weighed equal to or just heavier than 98.24 gms. Then the other cylinder was substituted and the lifting continued. The opposite procedure was used in a descending series. The use of only one cylinder would have necessitated the handling of twice as many bearings as were used.

The series were not taken in any regular order but entirely at haphazard; the determining factor in the choosing of a series being the amount of time at our disposal. If we had sufficient time, a long series of short steps was chosen; while if our time was short, a short series of long steps was used. A different starting point was chosen for each successive revolution of the table. This was done so that, even though a subject knew an order fairly well, he would not be able to tell at what part of that order he had started. It was furthermore deemed advisable, on each revolution of the table, to allow the subject to make two judgments that were not recorded. This was done so that the movements of the wrist might become as automatic as possible and also to give the subject an opportunity to concentrate his attention.

At the beginning of experimentation each day, the subjects made one complete revolution of the table grasping the weights as strongly as possible and lifting them high and vigorously. This was done for a double purpose: it assured the experimenter that the weights were in the correct position on the table in relation to the hand of the subject. At the beginning of experimentation, the weights give the impression of great lightness which is lost as the lifting process proceeds. This process can be hastened by the sort of lifting just described, and after such a warming up, both subjects made introspections that they had little trouble with the absolute impression.

After each five to seven revolutions of the table, the subject was allowed to rest, until he was willing to resume experimentation. If a subject declared that he felt fatigued or unfit he was not asked to experiment.

In the manner just described, results by the method of just perceptible differences were taken simultaneously, and therefore under as nearly indentical conditions as possible, with results by means of the method of constant stimuli. The former are the results obtained with the weight C and a standard weight, and the latter are the judgments on the six other pairs of weights.

Immediately after each comparison weight had been replaced on the table, a judgment was given in terms of the comparison weight. These judgments were given verbally and by saying one word, three terms being used: heavier, equal and lighter. A heavier judgment signified that the comparison weight was subjectively heavier than the standard weight just preceding it.

A lighter judgment signified that the comparison weight was subjectively lighter than the standard weight just preceding it. The equality judgment was more complex as it not only included cases of actual subjective equality between the standard and comparison weights, but also all those cases where it was impossible for the subject to give either a lighter or a heavier judgment, usually termed doubtful cases. The cases of absolute subjective equality were much more frequent with subject I than with subject II.

The results were recorded by the experimenter on printed blanks of the following form:

| | | | |
|---|---|---|---|
| 96 | h | e | e |
| 104 | h | h | h |
| 108 | h | h | h |
| 84 | l | l | l |
| 92 | l | e | l |
| C | l<br>0 | l<br>6 | l<br>12 |
| 88 | l | l | l |

The first column of these blanks gives the comparison weights, C being the variable weight for the method of just perceptible differences. The succeeding columns give the judgments for a complete revolution of the table, H signifying a heavier; E an equal, and L a lighter judgment. The small numbers (0, 6, 12, etc.) indicate the number of bearings in the comparison weight C during that revolution of the table. The above chart is a portion of the record of a series VI, as the weight C is regularly varied by six bearings.

From Fechner down, there has been a great deal of discussion about the choice of judgments; Fechner himself, objecting to the use of the equality or doubtful judgments [*Elemente der Psychophysik,* I, 72, 94. *Revision der Hauptpunkte der Psychophysik,* 67]. He suggested that the equal and doubtful judgments be divided in half and that one half be added to the right and the other half to the wrong cases. This procedure was followed by

Fullerton and Cattell [*Perception of Small Differences,* pp. 59]. Merkel suggested that the equal judgments be not only excluded from the calculations but also from the records [*Philosophische Studien,* IV, 131] and this method was followed out by Kraepelin in his experimental procedure [*Philosophische Studien,* VI, pp. 496]. Jastrow [*Amer. Jour. of Psych.,* I, 282] and Higier [*Phil. Stud.,* VII, 247] contended that there should be no equal or doubtful judgments and that when the subject does not know whether the judgment should be greater or less, he should guess. Sanford [*Course,* pp. 357] follows this same procedure. Brown [*Judgment of Difference,* 1910] is the latest adherent of the exclusion of the equality or doubtful judgments. He even asserts that if the subject is forced to give a judgment of either greater or less, that he can do so. Brown apparently fails to notice that this places his uncertain judgments in exactly the same category as those of Jastrow where the subject is forced to guess. Nor should the numerical results of these variations differ widely from those of Fechner, because the laws of chance would give approximately an equal division of this class of judgments between the two other classes. The only difference is that Fechner makes this division frankly while the others hide it under the technicalities of experimental procedure.

Urban [*Application of Statistical Methods,* pp. 5] uses a very complicated system of judgments. He uses the classes of greater, equal and lighter. The degree of confidence with which the judgment is given is designated by the subject by the numerals 1, 2 or 3. Besides these he uses two guess classes, "Guess-heavier and guess-lighter". Later in the paper [*Stat. Meth.,* pp. 14] he states that this system is too complicated and that the guess judgments are not advisable as they afford a loophole for the subject who does not wish to commit himself. Among the men who favor the use of the equality judgment we find Ebbinghaus, Wundt and Müller.

Titchener [*Experimental Psychology,* vol. II, part II, pp. 290] points out the original reasons why the equal judgments were first excluded. He shows that it was because three classes presented difficulties in mathematical treatment that were at that time unsurmountable. But these difficulties have since been solved and a further exclusion of judgments of this class for that reason, he calls unscientific. Titchener further points out that we have the evidence of introspection of trustworthy observers that equal and doubtful judgments do actually occur. "If we are dealing with mind as mind presents itself to us for examination, we cannot ignore these judgments." This seems to be an unanswerable criticism. Brown, in his paper, gives a case of subjective equality. His subject stated [*Judgment of Difference,* pp. 30] "those two are exactly the same". This may have been only one case in 4000, as Brown states, but still it must be accounted for. The subjects in our experiment both reported actual subjective equality; subject I gave this introspection quite frequently. The criticism of Brown [pp. 28] that the classes should be mutually exclusive is just as applicable to three classes as to two. His criticism that [pp. 32], for the equality judgment, the subject must maintain a mental standard of equality is not very impressive. Undoubtedly the subject must maintain such a standard, but he must also maintain, in the same sense, a standard for heaviness and lightness.

The classes of judgments chosen for this experiment fulfil all the requirements of the case. They are susceptible to mathematical treatment and they are not so complicated that the subject has any difficulty in giving them. The subject is not put to the strain of forcing a guess judgment. Lastly and of primary importance they fit the facts of actual experience.

## III. METHOD OF CONSTANT STIMULI

The record sheets enable us to find the relative frequencies of the heavier, equal and lighter judgments for all of the six comparison weights. In order to study the effect of practice, these observed frequencies were divided into groups of 100 in the order in which they were taken. These results are given in Table III for subject I and in Table IV for subject II. The numbers in the first column give the groups of 100 judgments in the order in which they were taken. Three columns are given to each comparison weight in which appear the lighter, equal and heavier frequencies of the judgments on that weight. The numbers in the same columns show, on the whole, a rather close agreement, but that they are by no means identical. For this reason it is not possible to say offhand whether a constant effect of practice has taken place or whether the conditions remain the same. This decision may be affected in two ways; by the determination of the coefficient of divergence for the probabilities for the different judgments, and by the determination of the constants for the psychometric functions.

The data in tables III and IV are results of repeated observations of certain unknown probabilities and the question arises whether the conditions, which determine these probabilities, remain the same or undergo variations. The coefficient of divergence [Lexis and Dormoy] enables us to make this decision systematically. If the coefficient gives a value close to unity we have a normal dispersion, and may know that the conditions have been approximately constant during the experiment. If the coefficient of divergence is considerably smaller than unity we obtain an under normal dispersion and we conclude that there is a law or rule which tends to produce always the same value of the relative frequencies. If the value comes out considerably greater than one, we speak of a more than normal or over normal dispersion which indicates that the conditions during the experiment have varied. We may illustrate these three kinds of dispersion by

|  | 84 |  |  | 88 |  |  | 92 |  |  | 96 |  |  | 104 |  |  | 108 |  |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Hundreds | Lighter | Equal | Heavier | Lighter | Equal | Heavier | Lighter | Equal | Heavier | Lighter | Equal | Heavier | Lighter | Equal | Heavier | Lighter | Equal | Heavier |
| 1 ........ | 0.94 | 0.05 | 0.01 | 0.83 | 0.16 | 0.01 | 0.55 | 0.32 | 0.13 | 0.35 | 0.44 | 0.21 | 0.06 | 0.21 | 0.73 | 0.00 | 0.08 | 0.92 |
| 2 ........ | 0.94 | 0.06 | 0.00 | 0.78 | 0.21 | 0.01 | 0.69 | 0.21 | 0.10 | 0.32 | 0.40 | 0.28 | 0.06 | 0.18 | 0.76 | 0.02 | 0.07 | 0.91 |
| 3 ........ | 0.96 | 0.04 | 0.00 | 0.90 | 0.08 | 0.02 | 0.60 | 0.23 | 0.17 | 0.37 | 0.41 | 0.22 | 0.02 | 0.15 | 0.83 | 0.03 | 0.06 | 0.91 |
| 4 ........ | 0.93 | 0.07 | 0.00 | 0.93 | 0.07 | 0.00 | 0.80 | 0.13 | 0.07 | 0.33 | 0.42 | 0.25 | 0.07 | 0.16 | 0.77 | 0.03 | 0.06 | 0.91 |
| 5 ........ | 0.97 | 0.03 | 0.00 | 0.81 | 0.18 | 0.01 | 0.61 | 0.32 | 0.07 | 0.37 | 0.34 | 0.29 | 0.02 | 0.16 | 0.82 | 0.02 | 0.04 | 0.94 |
| 6 ........ | 0.98 | 0.01 | 0.01 | 0.80 | 0.16 | 0.04 | 0.57 | 0.26 | 0.17 | 0.39 | 0.42 | 0.19 | 0.09 | 0.16 | 0.75 | 0.02 | 0.04 | 0.94 |
| 7 ........ | 0.95 | 0.05 | 0.00 | 0.91 | 0.05 | 0.04 | 0.60 | 0.25 | 0.15 | 0.46 | 0.37 | 0.17 | 0.09 | 0.17 | 0.74 | 0.01 | 0.04 | 0.95 |
| 8 ........ | 0.98 | 0.02 | 0.00 | 0.89 | 0.10 | 0.01 | 0.60 | 0.23 | 0.17 | 0.45 | 0.32 | 0.23 | 0.06 | 0.13 | 0.81 | 0.03 | 0.06 | 0.91 |
| 9 ........ | 0.95 | 0.04 | 0.01 | 0.88 | 0.11 | 0.01 | 0.69 | 0.25 | 0.06 | 0.42 | 0.31 | 0.27 | 0.07 | 0.12 | 0.81 | 0.00 | 0.02 | 0.98 |
| 10 ........ | 0.99 | 0.01 | 0.00 | 0.92 | 0.06 | 0.02 | 0.76 | 0.17 | 0.07 | 0.47 | 0.33 | 0.20 | 0.10 | 0.11 | 0.79 | 0.00 | 0.06 | 0.94 |
| 11 ........ | 0.96 | 0.03 | 0.01 | 0.83 | 0.15 | 0.02 | 0.56 | 0.36 | 0.08 | 0.41 | 0.36 | 0.23 | 0.11 | 0.14 | 0.75 | 0.03 | 0.04 | 0.93 |
| 12 ........ | 1.00 | 0.00 | 0.00 | 0.90 | 0.09 | 0.01 | 0.63 | 0.23 | 0.14 | 0.50 | 0.35 | 0.15 | 0.05 | 0.16 | 0.79 | 0.01 | 0.09 | 0.90 |
| 13 ........ | 1.00 | 0.00 | 0.00 | 0.94 | 0.06 | 0.00 | 0.72 | 0.21 | 0.07 | 0.49 | 0.41 | 0.10 | 0.07 | 0.18 | 0.75 | 0.00 | 0.03 | 0.97 |
| 14 ........ | 0.97 | 0.02 | 0.01 | 0.91 | 0.08 | 0.01 | 0.63 | 0.26 | 0.11 | 0.45 | 0.40 | 0.15 | 0.03 | 0.14 | 0.83 | 0.02 | 0.12 | 0.86 |

TABLE III

| | 84 | | | 88 | | | 92 | | | 96 | | | 104 | | | 108 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Hundreds | Lighter | Equal | Heavier | Lighter | Equal | Heavier | Lighter | Equal | Heavier | Lighter | Equal | Heavier | Lighter | Equal | Heavier | Lighter | Equal | Heavier |
| 1 ........ | 0.85 | 0.09 | 0.06 | 0.70 | 0.20 | 0.10 | 0.47 | 0.26 | 0.27 | 0.39 | 0.19 | 0.42 | 0.14 | 0.08 | 0.78 | 0.03 | 0.08 | 0.89 |
| 2 ........ | 0.94 | 0.03 | 0.03 | 0.77 | 0.17 | 0.06 | 0.60 | 0.24 | 0.16 | 0.49 | 0.27 | 0.24 | 0.10 | 0.12 | 0.78 | 0.04 | 0.08 | 0.88 |
| 3 ........ | 0.97 | 0.02 | 0.01 | 0.91 | 0.04 | 0.05 | 0.64 | 0.19 | 0.17 | 0.47 | 0.22 | 0.31 | 0.05 | 0.10 | 0.85 | 0.04 | 0.04 | 0.92 |
| 4 ........ | 0.99 | 0.00 | 0.01 | 0.90 | 0.09 | 0.01 | 0.63 | 0.23 | 0.14 | 0.42 | 0.26 | 0.32 | 0.01 | 0.09 | 0.90 | 0.01 | 0.03 | 0.96 |
| 5 ........ | 0.96 | 0.04 | 0.00 | 0.88 | 0.07 | 0.05 | 0.54 | 0.26 | 0.20 | 0.47 | 0.26 | 0.27 | 0.00 | 0.08 | 0.92 | 0.01 | 0.03 | 0.96 |
| 6 ........ | 1.00 | 0.00 | 0.00 | 0.85 | 0.13 | 0.02 | 0.58 | 0.28 | 0.14 | 0.37 | 0.31 | 0.32 | 0.01 | 0.03 | 0.96 | 0.00 | 0.04 | 0.96 |
| 7 ........ | 0.95 | 0.05 | 0.00 | 0.79 | 0.16 | 0.05 | 0.59 | 0.26 | 0.15 | 0.38 | 0.33 | 0.29 | 0.03 | 0.12 | 0.85 | 0.03 | 0.06 | 0.91 |
| 8 ........ | 0.95 | 0.04 | 0.01 | 0.79 | 0.17 | 0.04 | 0.56 | 0.29 | 0.15 | 0.26 | 0.36 | 0.38 | 0.02 | 0.13 | 0.85 | 0.01 | 0.09 | 0.90 |
| 9 ........ | 0.94 | 0.06 | 0.00 | 0.82 | 0.14 | 0.04 | 0.55 | 0.33 | 0.12 | 0.25 | 0.37 | 0.38 | 0.03 | 0.14 | 0.83 | 0.01 | 0.04 | 0.95 |
| 10 ........ | 0.98 | 0.02 | 0.00 | 0.84 | 0.14 | 0.02 | 0.61 | 0.19 | 0.20 | 0.28 | 0.37 | 0.35 | 0.07 | 0.15 | 0.78 | 0.02 | 0.07 | 0.91 |
| 11 ........ | 1.00 | 0.00 | 0.00 | 0.75 | 0.23 | 0.02 | 0.52 | 0.30 | 0.18 | 0.31 | 0.35 | 0.34 | 0.05 | 0.14 | 0.81 | 0.00 | 0.03 | 0.97 |
| 12 ........ | 0.97 | 0.03 | 0.00 | 0.89 | 0.09 | 0.02 | 0.69 | 0.23 | 0.08 | 0.32 | 0.47 | 0.21 | 0.08 | 0.19 | 0.73 | 0.02 | 0.09 | 0.89 |
| 13 ........ | 0.96 | 0.03 | 0.01 | 0.90 | 0.08 | 0.02 | 0.68 | 0.23 | 0.09 | 0.30 | 0.40 | 0.30 | 0.05 | 0.33 | 0.62 | 0.00 | 0.03 | 0.97 |
| 14 ........ | 0.98 | 0.02 | 0.00 | 0.88 | 0.12 | 0.00 | 0.66 | 0.28 | 0.06 | 0.46 | 0.33 | 0.21 | 0.03 | 0.15 | 0.82 | 0.01 | 0.07 | 0.92 |

TABLE IV

considering the drawing from an urn of black and white balls of a given relative frequency. Several urns are prepared and n numbers of drawings are made from each urn, and each ball is replaced after its colour has been noted. Under such conditions if the number of drawings is great enough, we will obtain a coefficient of divergence approximating unity, or in other words, a normal dispersion. An over normal dispersion will be obtained when the urns, before the drawings are made, contain different relative frequencies of black and white balls. Again each ball will be replaced in the urn after its colour has been noted and the same number of drawings will be made from each urn. But the varying frequencies in the urns represent changed conditions so that our results will give a coefficient of divergence greater than unity. If we can by some kind of device eliminate certain cases we will obtain an undernormal dispersion. For example, if we decide that every time three white or black balls are drawn in succession we shall record the third ball as having the opposite colour, we would obtain a coefficient of divergence less than unity. From this we conclude that in an under normal dispersion the results have been tampered with in some way. We must calculate the coefficient of divergence for the probabilities of each judgment for every intensity of the comparison stimulus that we used. The formula by which the coefficient of divergence is caluclated is

$$Q = \sqrt{\frac{s \Sigma v^2}{(n-1)\ p(1-p)}}$$

in which s is the number of observations in each series; $\Sigma v^2$ is the sum of the deviations of the relative frequencies from their average, n is the number of series and p the average of the relative frequencies, which is the most probable determination of the probability of the judgment. The quantity (1 — p) will then be the probability that this judgment will not occur. Table V is a double table that gives the coefficients of divergence for both subjects I and II. In the first column are found the intensities of the comparison weights. The next three columns give the coefficients of divergence for the heavier, lighter and equal judgments for subject I. In the vertical column, headed Average, is given the average of the coefficients of all three judgments for

|  | Subject I |  |  |  | Subject II |  |  |  |
|---|---|---|---|---|---|---|---|---|
| Stimulus | Lighter Judgments | Equal Judgments | Heavier Judgments | Average | Lighter Judgments | Equal Judgments | Heavier Judgments | Average |
| 84 | 1.236 | 1.223 | 0.935 | 1.131 | 0.582 | 1.387 | 1.720 | 1.230 |
| 88 | 1.531 | 1.568 | 0.971 | 1.357 | 1.690 | 1.517 | 1.243 | 1.483 |
| 92 | 1.544 | 1.346 | 1.306 | 1.399 | 1.238 | 0.883 | 1.464 | 1.195 |
| 96 | 1.157 | 0.842 | 1.292 | 1.097 | 1.672 | 1.551 | 1.313 | 1.512 |
| 104 | 1.100 | 0.699 | 0.815 | 0.871 | 1.752 | 1.970 | 2.108 | 1.943 |
| 108 | 1.004 | 1.087 | 1.124 | 1.072 | 1.116 | 0.996 | 1.216 | 1.109 |
| Average | 1.262 | 1.128 | 1.074 | 1.154 | 1.342 | 1.384 | 1.511 | 1.412 |

TABLE V

each comparison weight; and in the horizontal column we find the averages of the vertical columns. The last value of the horizontal averages is the total average of all the coefficients of divergence. The second half of the table shows a similar distribution for subject II.

In the case of subject I, the total average, 1.154, is well within the limits of what may be considered a normal dispersion, which indicates that the conditions remained constant for this subject. Such individual variations as the coefficient for the equal judgments of the 88 gm. weight [1.568] or that for the equal judgments of the 104 weight [0.699] may be accounted for by the chance variations of the results. The values of the coefficient of divergence are dependent, to a certain extent, upon the size of the sum of the deviations. It will be noted that all of the averages for subject I are outside of the limits of what must be considered an over normal dispersion.

For subject II, on the other hand, the total average is 1.412, which indicates a somewhat overnormal dispersion. All of the averages but one, the average for the 92 weight, are higher than the corresponding values for subject I. Four of the averages for subject II are above the limit for the over normal dispersion and two others are just below it, so that they almost certainly indicate the same tendency. This result indicates that a change in the conditions which determine the probabilities of the different judgments has taken place and we will have to consider what this change may have been.

The passing of a certain judgment may be dependent upon either the physical conditions of the experiment or upon the psychophysical make up of the subject, or to a complex of both influences. The physical conditions of the experiment remained as constant as it was possible to control them, hence the variations must have had their origin within the subject himself. We may liken the psychophysical make up of an individual to our example of the black and white balls in an urn, in which those psychophysical influences that control the passing of a certain judgment are likened to the balls. Now if these influences remain constant we will obtain a normal dispersion as in the first example where the relative frequencies of the white and black balls in the urns were the same. The normal dispersion for subject I would indicate such a constancy of conditions. The overnormal dispersion in the results of subject II indicates an influence which was at work in this subject but not in subject I, who showed approximately a normal dispersion. The changes in subject II may be likened to the case where the relative frequencies of the black and white balls varied for the different urns, and it seems to be an obvious idea to see this influence in the progressive practice acquired during the experiments. It will be remembered that subject I was very highly trained in the lifting of weights; while subject II had only one day's training at the start of the experiment; just enough to enable his hand movements to become somewhat automatic. It is, therefore, very likely that the changes in the conditions, as indicated by the coefficients of divergence, were due to the effect of practice. Similar results were found by Urban [Psych. Massmeth., *Arch. f. ges. Psych.*, XV, p. 283], where it was found that the subjects with the most considerable training showed very nearly a normal dispersion.

The changed conditions, as indicated by the coefficient of divergence greater than unity, may be due to a complex of four influences: first, a change in the sensitivity; second, to an unconscious learning of the order of the stimuli; third, to fatigue; and fourth, to the effect of practice. Practice itself is a complex of two elements that are, however, closely related and dependent upon one another; first, the acquiring of the automatic movements of the hand and by this the direct effect of the elimination of the space error and constancy of the time error. Second, the directing of the entire attention on the judgments, when it is no longer necessary to direct some of it upon the hand movements.

It is possible that there may be a certain training of the sensitivity in the same way that we may have training in a muscle, bringing with it increased efficiency. The sense organs employed in this experiment, the end organs of touch in the hand and the free nerve endings in the wrist and the forearm, are end organs constantly in use. So it is reasonable to believe that they are normally at a high state of efficiency so that this factor of the training of these sense organs cannot be of considerable extent.

The influence of fatigue could not have been great, as during the entire time of the lifting, we endeavored to eliminate this factor by resting the subject after every 5-7 revolutions of the table. Besides, the passing of a judgment on the intensities of two weights where the differences were as small as in this experiment, would be impossible in a state of fatigue, since in that case, the judgment would really become nothing but a guess. But even if we have present some influence of fatigue, this would be practically eliminated, since we are comparing groups of 100 experiments, each of which represent three or four days' experimentation. Thus there would be several places in the series, where the subject was fresh and as many places where he was fatigued, and these influences would tend to cancel one another.

It seems a reasonable expectation that the effect of practice would be greatest in the beginning of the experiments and that the conditions should remain constant after a certain perfection is attained. In order to test this supposition, the coefficient of divergence was calculated for subject II for the last 13 groups, omitting the first group of 100 experiments. The amount of work in this second set of calculations, can be greatly reduced by deriving the new sum of the squares of the deviations from the values already ascertained. This step, which is the one that requires the most time in the calculations, may be accomplished by applying the formula

$$\Sigma\, v^2_1 = \Sigma\, v^2 + nd - (A^1 - a)^2 \,.$$

In this formula, n represents the number of groups; d the difference between the average of the 14 groups and the average of the 13 groups, which latter is represented by $A^1$; and finally, a stands for the omitted result.

Table VI, which has the same form as table V, gives the new values of the coefficient of divergence for subject II for the last 13 groups only. It will be noticed that, although the individual values change, the total average for the two sets of calculations for this subject are almost identical. This would indicate that the changed condition, whatever it may be, did not have its greatest effect in the first series. Where an individual coefficient in table VI is smaller than the corresponding value in table V, it

| | Subject II | | | |
|---|---|---|---|---|
| Stimulus | Lighter Judgments | Equal Judgments | Heavier Judgments | Average |
| 84 | 1.180 | 1.223 | 1.306 | 1.236 |
| 88 | 2.473 | 1.551 | 0.906 | 1.643 |
| 92 | 1.107 | 0.953 | 1.265 | 1.108 |
| 96 | 1.802 | 1.440 | 1.236 | 1.493 |
| 104 | 1.492 | 2.051 | 2.282 | 1.942 |
| 108 | 1.195 | 1.047 | 1.262 | 1.168 |
| Average | 1.542 | 1.377 | 1.376 | 1.432 |

Table VI

indicates that the deviation in the first series was large. The opposite holds for the cases where the terms in table VI are larger than those in the former calculation. It will be seen, however, by the averages that, on the whole, these variations almost cancel one another. If the over normal dispersion was due to the effect of practice, we may know that this was not as rapid in the first series as might have been expected, but that it was gradual throughout the experiment.

A further treatment of the coefficient of divergence strengthens the belief in the importance of the concentrating of the attention upon the judgments. If the averages for each intensity of the comparison stimulus for both subjects are averaged, we obtain the values

84 — 1.180
88 — 1.415
92 — 1.295
96 — 1.402
104 — 1.329
108 — 1.116

It will be noticed that for the extreme values of the comparison stimulus, the averages of the coefficients of divergence are small and that, with the exception of the average for the 92 weight, they gradually rise toward the central values. Considering the fact that these are averages of the results of only two subjects, it is remarkable that this course should be broken at only one place. The explanation of this set of values seems to lie in the fact that it takes less concentration of the attention to judge the difference between an 84 or a 108 gram weight and a standard weight of 100 grams; than it would between the same standard weight and a comparison stimulus that was but little different from it. So at the start of the experiment, subject II could give enough attention to the judgments on the extreme intensities of the comparison weight to have these judgments fairly accurate. It required, however, so much more attention to give correct judgments on the central values that, at the start of the experiment, these were judged much more inaccurately. Later when more attention could be given to the judgments, the central values could be judged more accurately, while there could be little change in the extreme values, as they had been judged with a fair degree of accuracy from the beginning. Thus there was greater variation for the central values than for the extreme ones, and this fact is shown by the size of the coefficients of divergence for the different intensities of the comparison stimulus.

Although the two elements of the automatic movements of the hand and the increased attention on the judgments are interrelated, still it does not imply that when the automatism is perfect, that we have at once a maximal attention on the judgments. It is our belief that for subject II, the hand movements became automatic very early in the experiment and this led us to calculate the coefficient of divergence for this subject for the last 13 groups of experiments. We found, however, but little change in the value obtained from that corresponding value for all of the experiments. This would indicate that the element of practice of the automatic hand movements is not of very great direct importance. This element, however, is fundamental for that of the proper direction of the attention upon the judgments, as the latter influence implies that the automatisms have reached a degree of perfection.

The coefficient of divergence merely shows that a change in the conditions has taken place. It furthermore, indicates the nature of this change but, by no means, can it be taken as conclusive evidence. The examination of the constants of the psychometric functions of the two subjects will give us a chance to study this variation a little more closely. The psychometric functions for the heavier judgments gives the probability of a heavier judgment as function of the intensity of the comparison stimulus. Similarly the psychometric functions for the lighter judgments gives the probability of a lighter judgment; and for the equal judgments gives the probability of an equal judgment, as function of the intensity of the comparison stimulus. If the psychometric functions with all their constants are given, we are able to calculate the probabilities of the different judgments for every intensity of the comparison stimulus. We may represent the course of the psychometric functions graphically, by constructing the comparison weights on the abcissa and the corresponding probabilities of the different judgments as ordinates. The curve representing the psychometric functions for the lighter judgments will set in with high values [close to unity], and will drop at first slowly, then more rapidly and eventually it will approach the abcissa asymtotically. The psychometric functions for the heavier judgments will have just the opposite course, setting in with low values and attaining the values close to unity for the high intensities of the comparison stimulus. The curve for the psychometric functions of the equality judgments starts with low values, then rises to a maximum and finally falls off very rapidly. A diagram of this kind enables us to see the variations of the probabilities of the different judgments at a glance.

It would be the same if we were to get an analytic expression to express this set of facts. The choice of such a mathematical formula will be in the nature of a hypothesis about the psychometric functions. The one chief requisite of such an expression is that it fits the facts of the observed frequencies. Several such hypotheses can be advanced but they do not fit the facts of lifted weights, for example, as was shown by Urban in regard to the Lagrange formula [Method of Constant Stim., *Psych. Review,* XVII, p. 234]. The $\Phi(\gamma)$ hypothesis recommends itself, however, by its simplicity and the fact that it is known by large experience. This experience has also shown that the $\Phi(\gamma)$ hypothesis comes very near the truth in so far as lifted weights are concerned. This hypothesis underlies the method of constant stimuli, which is essentially nothing else but the determination of the quantities h and c, two values upon which the form and position of the curves of the psychometric functions depend. The greater the value of h, the steeper the curve is and thus the h exerts an influence upon the form of the curve. The influence of c upon the position of the curve is such that a larger c means the shifting of the entire curve to the left. The essential feature of the $\Phi(\gamma)$ hypothesis is that only the values of the extreme judgments are calculated. The values of the equality judgments are found by the difference from unity of the sum of the probabilities of the heavier and lighter judgments. The extreme judgments are those which are greater or less. The intermediate judgments admitted in any study must be odd in number and in this study it was limited to one, the equality judgment. The $\Phi(\gamma)$ hypothesis consists in the supposition that the psychometric functions of the smaller judgments are represented by expressions of the form

$$p = \tfrac{1}{2}\,[1 - \Phi\,(h_1\,x - c_1)],$$

and for the greater judgments by

$$p^1 = \tfrac{1}{2}\,[1 + \Phi\,(h_2\,x - c_2)].$$

In these equations x represents the intensity of the comparison stimulus and $\Phi$ has the sign of its argument. If we substitute the relative frequencies of one of the extreme judgments, e. g. of the lighter judgments, for the values of the comparison stimulus used in our experiments, we obtain a series of equations of the form

$$p_{84} = \tfrac{1}{2}\,[1 - \Phi\,(h\,x_{84} - c)]$$
$$p_{88} = \tfrac{1}{2}\,[1 - \Phi\,(h\,x_{88} - c)]$$

. . . . . . . . . . . . . . . . . . . . . . . . . . . . .

from which we have to determine the unknown quantities h and c. It is not possible to solve these equations in this form and so they are changed to read

$$\Phi\,(h\,x_{84} - c) = \frac{2p_{84} - 1}{2}$$

$$\Phi\,(h\,x_{88} - c) = \frac{2p_{88} - 1}{2}$$

. . . . . . . . . . . . . . . . . . . . . . . . . . .

from which the arguments (hx — c) may be determined, which is the form to be used in our observation equations. The relative frequencies for all the judgments of all the six comparison stimuli are found in tables III and VI. The values of $\Phi(\gamma)$ corresponding to these relative frequencies are found either in a table of the probability integral or in the so-called fundamental table for the method of right and wrong cases that was calculated by Fechner. It was found that many of the values in Fechner's original table were wrong in the last decimal place because the tables of the probability integral that were in Fechner's possession were not complete. With the appearance of complete tables of the probability integral by Bruns [*Wahrscheinlichkeitsrechnung und Kollektivmasslehre.*, 1906], the fundamental table was recalculated by Urban [Method of constant stimuli, *Psych. Rev.,* XVII, p. 251]. This situation was not understood by Brown [*Mental Measurement,* p. 134, 1911], who prints this table and states that it was calculated by Bruns and quoted by Urban.

These determinations of unknown probabilities, however, are not exactly correct and unless these differences are allowed for, certain discrepancies will appear in the results. To eliminate these errors, each observation equation is given a weight, which is in relation to the probable errors of the observed relative frequencies. G. E. Müller was the first to see that these observation equations are not of the same weight, but did not arrive at the correct formula. Urban took up this analysis and published a table of these weights, calculated by another formula [*Psych. Review,* XVII, p. 253, and *Arch. f. ges. Psych.,* XVI, p. 371. also quoted by Brown, *Mental Measurements,* p. 135].

The values for $\gamma$ are substituted in the observation equations and it is found to be convenient to write the weight or P after each equation. Thus we obtain an observation equation and a weight for each of the six comparison stimuli used, in this form

$$\begin{aligned} hx_1 - c &= \gamma_1 \text{ with weight } P_1 \\ hx_2 - c &= \gamma_2 \text{ with weight } P_2 \\ &\dots\dots\dots\dots \\ hx_6 - c &= \gamma_6 \text{ with weight } P_6. \end{aligned}$$

This gives an over determined set of equations for the determination of the constants h and c. The solution of this set, by the Method of Least Squares, gives the most probable values of the unknown quantities. For the purposes of calculation an adding machine was found to be invaluable. After some practice, it became possible, with the help of this machine, to effect the solution of such a set of observation equations in one and a quarter hours, which is considerably less than the time required to do the same calculation even with the help of logarithms.[1] The calculations are very easy but rather lengthy so that it is impossible to be sure of their correctness unless the whole work is arranged systematically [cf. Urban, *Arch. f. ges. Psych.,* XVI, pp. 375-377, and Wirth, *Psychophysik,* pp. 210-214]. The scheme used for this purpose is a modification of the Gaussian method for solving a system of equations by the method of least squares. The first step for this solution consists in setting up the normal equations which have the form:

$$[xxP]h - [xP]c = [x\gamma P]$$
$$-[xP]h + [P]c = -[\gamma P].$$

These normal equations require the calculation of the sums of the products xP, xxP, $\gamma$P, and x$\gamma$P. The sum of the P is found directly by addition. We obtain the products xP by multiplying each P by its corresponding x; their sum is designated by [xP]. The values xxP are obtained by multiplying each xP by the corresponding x, a multiplication which is performed on the adding machine in two steps without clearing the machine. The calculation of [$\gamma$P] and [x$\gamma$P] is similarly arranged. The products $\gamma$P are formed first and then used for the calculation of x$\gamma$P without clearing the machine.

These six sums are all the values that are necessary for the setting up of the normal equations for h and c. In order to check the correctness of these results, three other values are calculated. A quantity s is defined as the algebraic sum of all the coefficients of the observation equations, e. g. by

$$s = x - 1 - \gamma$$

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[1] Since the writing of this paper, Urban *(Hilfstabellen fur die Konstanzmethode. Arch. fur die ges. Psych. Bd.,* XXIV, 2-3 Heft, pp. 236-243) has printed a set of tables which are of great assistance in this kind of work. By means of these tables a set of equations can be solved in little more than half an hour.

notice being taken of the sign $\gamma$. Multiplying this equation by P we obtain

$$sP = xP - P - \gamma P.$$

If these products are formed for every observation equation and added we obtain

$$[sP] = [xP] - [P] - [\gamma P].$$

The terms on the right side of this equation are needed for setting up the normal equations and the calculation of the sum [sP] gives us a thoroughgoing check of our results for the other three sums. As all the decimal places were retained in the terms of this equation it must be expected to solve exactly. Multiplying the equation for s by xP gives

$$xsP = xxP - xP - x\gamma P$$

and by adding up these relations for all of the values of x we obtain

$$[xsP] = [xxP] - [xP] - [x\gamma P].$$

The terms on the right side of the equation are the sums which are used in the normal equations and the sum [xsP] affords a check on our calculations of these sums. Our calculations were arranged in such a way as to require this check to tally to the third decimal place. The check worked out in this way is a great saving of time as it requires only the calculation of three sums [s], [sP] and [xsP]; the s being calculated almost directly. The only other check would be a recalculation of the other five quantities. This would be not only more laborious but furthermore in such a recalculation, it would be quite possible to repeat an error that had been made before.

Tables VII and VIII give these sums for the lighter and heavier judgments respectively for subject I and tables IX and X are similarly constructed for subject II. The first columns give the number of groups of the hundred experiments into which the results were divided. The succeeding columns give in order the values of [P], [xP], [xxP], [$\gamma$P], [x$\gamma$P], [sP] and [xsP]. On account of the lack of space these tables are somewhat reduced, by omitting one decimal place for the values [xP], [xxP], [$\gamma$P], [x$\gamma$P] and [sP]; and two for the quantity [xsP]. All the

| Series | [P] | [xP] | [xxP] | [γP] | [γxP] | [sP] | [sxP] |
|---|---|---|---|---|---|---|---|
| 1 | 3.447 | 319.64 | 29748.02 | — 0.311 | —16.982 | 316.508 | 29445.37 |
| 2 | 3.619 | 338.00 | 31719.38 | — 0.182 | — 0.728 | 334.567 | 31382.10 |
| 3 | 3.215 | 301.26 | 28354.91 | — 0.211 | — 4.999 | 298.260 | 28058.64 |
| 4 | 3.256 | 307.26 | 29153.89 | — 0.291 | — 9.421 | 304.279 | 28856.04 |
| 5 | 3.307 | 308.32 | 28858.56 | — 0.222 | — 7.379 | 305.235 | 28557.62 |
| 6 | 3.611 | 340.59 | 32265.26 | 0.090 | 23.164 | 336.887 | 31901.51 |
| 7 | 3.449 | 324.32 | 30629.90 | — 0.330 | —16.133 | 321.197 | 30321.72 |
| 8 | 3.371 | 319.08 | 30337.04 | — 0.084 | 7.421 | 315.796 | 30010.62 |
| 9 | 3.281 | 305.82 | 28610.21 | — 0.630 | —46.667 | 303.165 | 28351.06 |
| 10 | 2.952 | 279.25 | 26504.06 | — 0.528 | —39.168 | 276.824 | 26263.98 |
| 11 | 3.806 | 359.58 | 34140.69 | 0.018 | 18.378 | 355.756 | 33762.73 |
| 12 | 2.962 | 280.37 | 26621.31 | — 0.119 | — 1.149 | 277.525 | 26342.09 |
| 13 | 2.714 | 257.32 | 24461.30 | — 0.328 | —22.878 | 254.938 | 24226.85 |
| 14 | 3.146 | 295.38 | 27845.12 | — 0.345 | —18.502 | 292.575 | 27568.24 |

Table VII

| Series | [P] | [xP] | [xxP] | [$\gamma$P] | [$\gamma$xP] | [sP] | [sxP] |
|---|---|---|---|---|---|---|---|
| 1 | 2.975 | 293.51 | 29092.88 | — 0.465 | —30.379 | 290.998 | 28829.75 |
| 2 | 2.871 | 285.30 | 28459.58 | — 0.140 | — 0.981 | 282.565 | 28165.27 |
| 3 | 2.922 | 287.94 | 28497.20 | — 0.230 | — 8.405 | 285.248 | 28217.66 |
| 4 | 2.605 | 260.96 | 26228.14 | 0.050 | 15.756 | 258.300 | 25951.19 |
| 5 | 2.570 | 254.70 | 25335.34 | — 0.078 | 4.803 | 252.208 | 25075.84 |
| 6 | 3.123 | 304.70 | 29878.99 | — 0.670 | —48.696 | 302.247 | 29622.98 |
| 7 | 2.898 | 284.19 | 27992.74 | — 0.548 | —39.625 | 281.842 | 27748.17 |
| 8 | 2.901 | 286.84 | 28476.46 | — 0.146 | — 1.135 | 284.081 | 28190.76 |
| 9 | 2.430 | 237.72 | 23351.30 | — 0.443 | —30.094 | 235.728 | 23143.58 |
| 10 | 2.575 | 255.01 | 25357.42 | — 0.300 | —15.960 | 252.737 | 25118.37 |
| 11 | 2.870 | 282.78 | 27996.27 | — 0.494 | —32.552 | 280.404 | 27746.04 |
| 12 | 2.753 | 273.56 | 27297.22 | — 0.232 | — 9.431 | 271.040 | 27033.08 |
| 13 | 2.068 | 206.54 | 20694.72 | — 0.207 | —10.838 | 204.683 | 20499.01 |
| 14 | 2.820 | 279.67 | 27878.16 | — 0.377 | —19.745 | 277.225 | 27619.24 |

Table VIII

| Series | [P] | [xP] | [xxP] | [γP] | [γxP] | [sP] | [sxP] |
|---|---|---|---|---|---|---|---|
| 1 | 4.439 | 415.04 | 39024.59 | 0.244 | 39.656 | 410.353 | 38569.90 |
| 2 | 4.033 | 379.92 | 35978.96 | — 0.156 | 2.771 | 376.039 | 35596.27 |
| 3 | 3.363 | 318.46 | 30300.72 | — 0.214 | — 3.962 | 315.307 | 29985.79 |
| 4 | 2.819 | 263.38 | 24677.50 | — 0.388 | —26.546 | 260.945 | 24440.67 |
| 5 | 3.005 | 277.43 | 25686.78 | — 0.704 | —57.119 | 275.131 | 25465.98 |
| 6 | 2.727 | 253.39 | 23584.27 | — 0.222 | —15.362 | 250.883 | 23346.24 |
| 7 | 3.585 | 334.70 | 31390.82 | — 0.145 | 1.862 | 331.256 | 31054.26 |
| 8 | 3.289 | 304.10 | 28220.03 | — 0.117 | 2.036 | 300.924 | 27913.90 |
| 9 | 3.331 | 308.52 | 28688.50 | — 0.079 | 6.622 | 305.264 | 28373.36 |
| 10 | 3.358 | 316.41 | 29944.67 | 0.138 | 28.056 | 312.912 | 29600.20 |
| 11 | 3.111 | 290.71 | 27237.62 | 0.291 | 34.752 | 287.306 | 26912.34 |
| 12 | 3.312 | 312.79 | 29676.58 | — 0.098 | 6.821 | 309.578 | 29356.96 |
| 13 | 3.021 | 281.19 | 26262.06 | — 0.424 | —27.844 | 278.592 | 26008.72 |
| 14 | 3.079 | 288.16 | 27062.00 | — 0.454 | —30.397 | 285.531 | 26804.24 |

Table IX

| Series | [P] | [xP] | [xxP] | [γP] | [γxP] | [sP] | [sxP] |
|---|---|---|---|---|---|---|---|
| 1 | 4.160 | 400.05 | 38709.09 | — 0.511 | —28.978 | 396.399 | 38338.02 |
| 2 | 3.569 | 347.26 | 33990.62 | — 0.737 | —51.923 | 344.424 | 33695.29 |
| 3 | 3.233 | 314.38 | 30726.54 | — 0.435 | —24.809 | 311.581 | 30436.84 |
| 4 | 2.635 | 256.09 | 24996.58 | — 0.303 | —15.042 | 253.756 | 24755.53 |
| 5 | 2.769 | 267.35 | 25921.31 | — 0.400 | —24.997 | 264.983 | 25678.95 |
| 6 | 2.364 | 228.94 | 22256.16 | — 0.317 | —18.810 | 226.897 | 22046.02 |
| 7 | 3.092 | 302.77 | 29784.58 | — 0.280 | —11.909 | 299.956 | 29493.72 |
| 8 | 3.261 | 318.42 | 31249.15 | — 0.282 | —10.101 | 315.437 | 30940.83 |
| 9 | 2.931 | 286.49 | 28119.66 | — 0.189 | — 4.406 | 283.750 | 27837.58 |
| 10 | 3.213 | 316.37 | 31280.19 | — 0.070 | 6.580 | 313.225 | 30957.24 |
| 11 | 2.861 | 279.23 | 27351.49 | — 0.232 | —10.461 | 276.593 | 27083.56 |
| 12 | 2.884 | 287.25 | 28730.35 | — 0.320 | —17.755 | 284.688 | 28460.85 |
| 13 | 2.925 | 286.66 | 28215.86 | — 0.730 | —58.191 | 284.466 | 27987.39 |
| 14 | 2.388 | 239.19 | 24038.27 | 0.059 | 16.861 | 236.745 | 23782.22 |

TABLE X

checks are fulfilled so that we are sure that no mistake has been made in the calculation of these sums.

These values are substituted in the normal equations which must be solved for the two unknown quantities h and c. It is found to be simplest in most cases to solve for h directly, and then substitute the value found, in the normal equation for c; as in this equation the terms are smaller. A check on this part of the work is effected by substituting the values obtained for h and c in the normal equation for h and observing whether the equation proves. This check will not come out exactly as only four decimal places are retained in the calculations, but we placed the arbitrary limit that the difference between the values of $[x\gamma P]$ obtained should not be greater than one per cent of that value.

After we have obtained the values of h and c, the calculation of the threshold is very simple. The threshold in the direction of increase is defined as that point in the curve of the heavier judgments where the probability of a heavier judgment is ½. Similarly that place in the curve for the lighter judgments where the probability of a lighter judgment is ½, defines the threshold in the direction of decrease. At such a point, according to the $\Phi(\gamma)$ hypothesis the value of $\gamma = 0$. Then

$$0 = hx - c.$$

Then we obtain the formula

$$S = \frac{c}{h}$$

which is used for the calculation of the threshold in the direction of increase if the h and c for the heavier judgments are used. If the constants for the lighter judgments are substituted in the formula, the S will be the threshold in the direction of decrease. Tables XI and XII give the h, c and S values for subjects I and II respectively. Opposite the numbers for the series, given in the first columns, will be found the values of h, c and S for first the lighter and then the heavier judgments. The columns headed $S_1$ contain the threshold in the direction of decrease and those headed $S_2$ give the threshold in the direction of increase.

| Series | Lighter Judgments | | | Heavier Judgments | | |
|---|---|---|---|---|---|---|
| | $h_1$ | $c_1$ | $S_1$ | $h_2$ | $c_2$ | $S_2$ |
| 1 | 0.11051 | 10.337 | 94.54 | 0.11371 | 11.374 | 100.03 |
| 2 | 0.10769 | 10.108 | 93.86 | 0.11914 | 11.888 | 99.78 |
| 3 | 0.11267 | 10.617 | 94.23 | 0.11629 | 11.537 | 99.21 |
| 4 | 0.10976 | 10.442 | 95.13 | 0.11734 | 11.731 | 99.98 |
| 5 | 0.11714 | 10.988 | 93.81 | 0.13496 | 13.406 | 99.33 |
| 6 | 0.10432 | 9.814 | 94.08 | 0.11059 | 11.004 | 99.50 |
| 7 | 0.11156 | 10.586 | 94.89 | 0.11393 | 11.362 | 99.72 |
| 8 | 0.11379 | 10.796 | 94.88 | 0.11641 | 11.560 | 99.30 |
| 9 | 0.11477 | 10.889 | 94.88 | 0.13843 | 13.724 | 99.14 |
| 10 | 0.12274 | 11.790 | 96.06 | 0.13364 | 13.351 | 99.90 |
| 11 | 0.09902 | 9.351 | 94.43 | 0.12086 | 12.081 | 99.95 |
| 12 | 0.12287 | 11.670 | 94.99 | 0.12004 | 12.012 | 100.07 |
| 13 | 0.12794 | 12.251 | 95.76 | 0.14643 | 14.725 | 100.56 |
| 14 | 0.12446 | 11.795 | 94.77 | 0.12390 | 12.421 | 100.25 |

Table XI

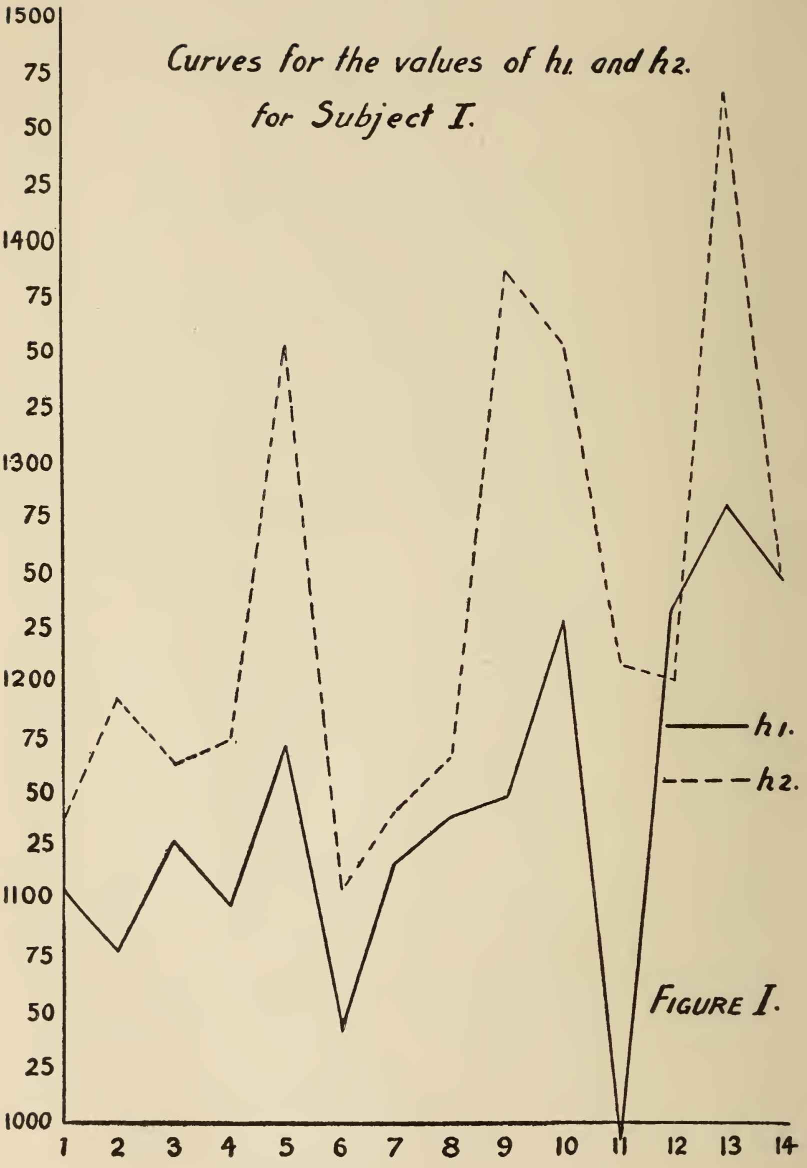
| Series | Lighter Judgments | | | Heavier Judgments | | |
|---|---|---|---|---|---|---|
| | $h_1$ | $c_1$ | $S_1$ | $h_2$ | $c_2$ | $S_2$ |
| 1 | 0.07570 | 7.023 | 92.77 | 0.08126 | 7.936 | 97.67 |
| 2 | 0.09224 | 8.728 | 94.62 | 0.09763 | 9.706 | 99.42 |
| 3 | 0.10859 | 10.338 | 95.22 | 0.10666 | 10.500 | 98.45 |
| 4 | 0.13786 | 13.018 | 94.42 | 0.12340 | 12.108 | 98.12 |
| 5 | 0.10672 | 10.087 | 94.52 | 0.12580 | 12.291 | 97.70 |
| 6 | 0.13459 | 12.587 | 93.52 | 0.14124 | 13.812 | 97.80 |
| 7 | 0.10743 | 10.070 | 93.74 | 0.11233 | 11.090 | 98.72 |
| 8 | 0.12512 | 11.604 | 92.73 | 0.11112 | 10.937 | 98.43 |
| 9 | 0.12402 | 11.511 | 92.81 | 0.12023 | 11.816 | 98.28 |
| 10 | 0.11502 | 10.797 | 93.87 | 0.10467 | 10.328 | 98.67 |
| 11 | 0.10223 | 9.460 | 92.53 | 0.12377 | 12.161 | 98.25 |
| 12 | 0.11750 | 11.126 | 94.70 | 0.11801 | 11.865 | 100.54 |
| 13 | 0.13071 | 12.307 | 94.16 | 0.10954 | 10.985 | 100.29 |
| 14 | 0.12920 | 12.239 | 94.73 | 0.13650 | 13.648 | 99.98 |

TABLE XII

By a close study of these two tables [XI and XII] we can discover many facts that were only hinted at in the results of the coefficient of divergence. We will consider the effect of the unconscious learning of the order of presentation of the stimuli. The order of the series was changed after the first, fifth and thirteenth groups of 100. If there was any effect of this knowledge of the series, we should expect to find that the h for the group immediately before the change would be larger than the h in the group following. As has been noted above, the h controls the steepness of the curves and with a knowledge of the order we may expect a greater accuracy in the judgments. An examination of the tables will show that for subject I, the h's for the groups immediately after these changes are slightly smaller for the most part, than those of the series just preceding, but this is not true for subject II. This would indicate that for the latter, the influence of the knowledge of the order was of no consequence. For subject I this knowledge may have had some effect upon the results, but as the differences are small this effect was not considerable.

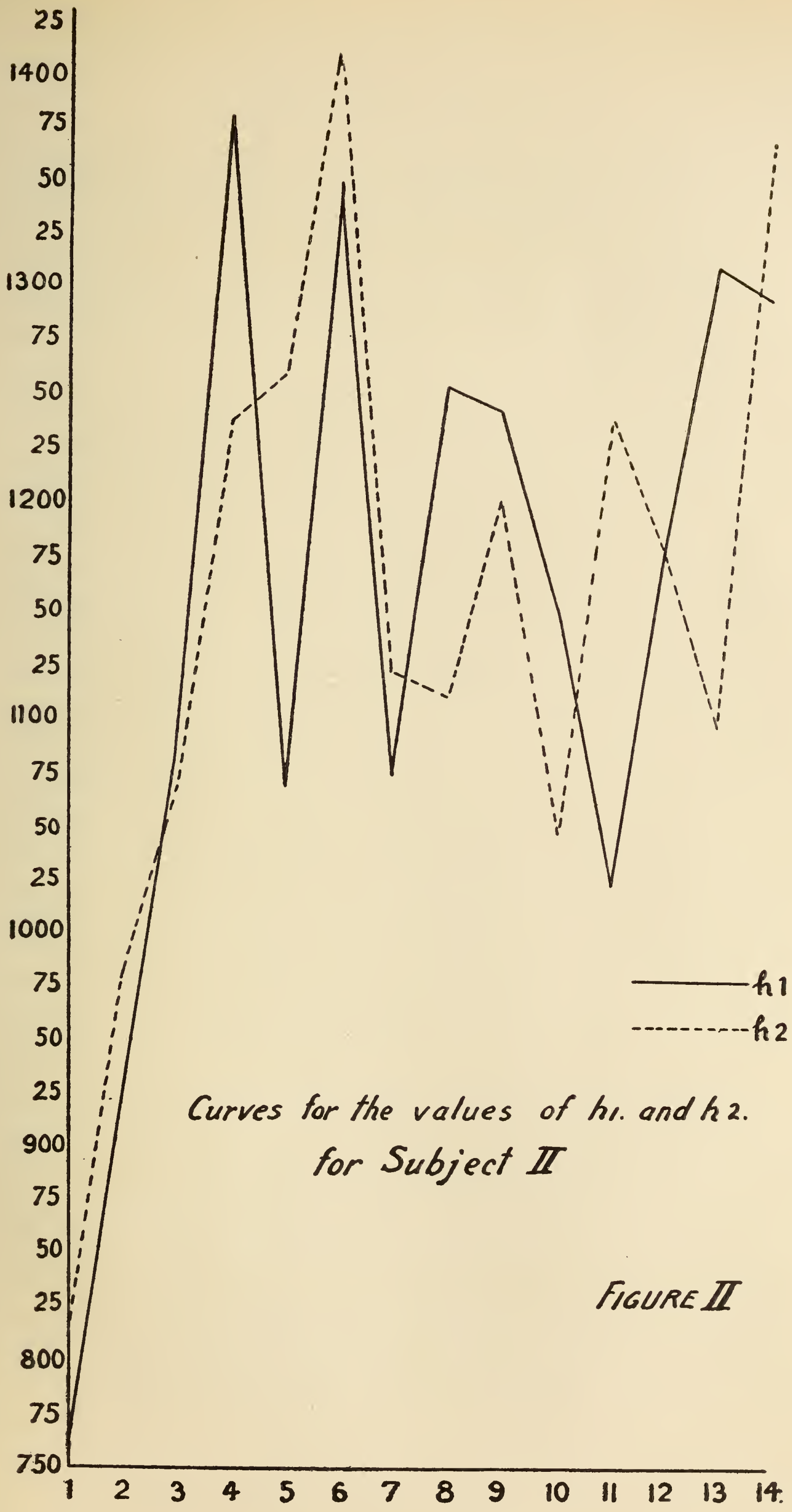
For the convenience of studying the effect of practice, it was deemed advisable to plot the four curves of the course of the h's shown in figures I and II. Upon the abcissa are laid off the series in order; while the ordinates represent the values of h. These curves are strikingly different in form when we compare those of the different subjects; but for the the same subject they are quite similar in character. Although all the curves show unsystematic variations, the curves for subject I start with values that are fairly high and the general trend is upward. This is particularly noticeable in the curve $h_2$ for subject I. The curves $h_1$ and $h_2$ for the other subject start with comparatively small values and, for the first four groups with $h_1$, and the first six groups for $h_2$, they show a very rapid rise. Both curves then fall from this maximum, and from the seventh series on, show a very gradual upward tendency.

For reasons stated above we have ruled out the influence of the knowledge of the orders as being negligible. Changes in sensitivity, due to the weather conditions, the tone of the subject and



Curves for the values of $h_1$ and $h_2$ for Subject I.

FIGURE I.



*Curves for the values of h1. and h2. for Subject II*

FIGURE II

like influences may account for the unsystematic variations or the chance irregularities in the curves. But we have still to account for the systematic tendencies that give the curves for the two subjects their distinctive character. We have eliminated all of the factors that could influence our judgments except that of practice; in fact the curves for subject II might be taken for typical practice curves.

This agrees with the facts regarding the subjects themselves, as it will be remembered that subject II was absolutely untrained at the start of the experiment; while subject I was highly trained, due to his having acted as subject in previous experiments. The values of h start high for the latter, but, in spite of all his former practice, the curve for subject I still shows a gradual rise. The curves for subject II indicate, by their rapid rise in the first six series, that during this time the subject became practised in the method of lifting the weights. This means that the hand movements became so automatic that the space error was entirely eliminated. This may perhaps need some explanation. At the start of the experiment there was a tendency on the part of subject II to turn his hand slightly in the direction from which the weights approached, and thus a space error, even though a slight one, was committed. This, however, was subsequently eliminated when the hand movements of the subject became automatic, and therefore accurate in regard to movement in space. The hand movements improved in regularity as to time and so the time error became more constant as the experiment proceeded. There was still another effect of the perfecting of the automatism, since when perfected it no longer requires any of the attention of the subject, and this then, can be entirely focused on the judgments. In this connection, it will be remembered, that the results of the calculation of the coefficient of divergence argue for the same notion. The drop in the curves after the maximum had been reached cannot be accounted for unless the maximum itself is caused by a chance variation that accentuates it. If a similar curve be constructed for subject I from the results of the former experiment in which he acted as subject, it will show a similar rapid rise in the early series. Several years have elapsed between that experiment and this one. If the sense organs had been trained due to the practice several years ago, to a higher state of efficiency; it is reasonable to believe that due to the disuse during the interval between the experiments, they would have degenerated somewhat to the condition in which they were before they had received any training at all. The rise in the curves for subject II are not very great and this would argue against any considerable education of the sense organs.

It must further be remembered that the measure of the sensitivity of the sense organ is not to be found in the abruptness of the curve of the psychometric functions, h, but by the interval between the two thresholds. This is the basis of the practicability of the method of constant stimuli. An examination of Tables XI and XII will show that the thresholds remain fairly constant. These values show chance variations but it is impossible to discover systematic tendencies in their course. They remain conspicuously constant for subject I. Thus the training of the sense organ, which might directly effect the sensitivity seems to have little influence, if any, as the sensitivity remains very constant and at least shows no systematic variations. This is an important consideration, because if practice effected the measure of sensitivity, the method of constant stimuli would have to be abandoned as a practical means of arriving at that value. It will be noticed, however, that, although the values of the h and c vary considerably, $\frac{c}{h}$ the threshold, remains practically constant.

The characteristics of the curves for the two subjects agree with the values of the coefficient of divergence obtained for the same set of results. For subject I we obtain a coefficient of divergence that approximates unity more closely than that for subject II, and the curves of the former show not only smaller unsystematic variations, but smaller systematic ones as well. Our experiments were probably not extended enough to show long periodicity and the results were not regular enough to reveal short periodicity.

It then seems that the important variations in the curves of the h and c values are:

1. Those of an unsystematic or chance character, that are due to the condition of the subject and similar chance influences.

2. Variations of a systematic nature that seem to have their origin principally as the result of practice which allows a concentration of the attention primarily upon the judgments, when the hand movements become so automatic that they no longer require attention.

3. This effect of practice is not evenly distributed throughout the experiment, but for an untrained subject is comparatively great in the first few hundred experiments.

4. This effect of practice, however, does not seem to effect the real purpose of the experimentation, which is to ascertain the sensitivity of the subject, as the ratios that define the measure of sensitivity remain practically constant and show no systematic variations.

We will turn now from the study of the effect of practice, as shown in this set of results, to a consideration of the results themselves. The real purpose of the psychophysical methods is to ascertain the sensitivity of the subject. The problem is how much larger or how much smaller a comparison weight must be from the standard weight until a difference can be perceived between them. This statement implies that there is a distance on each side of the standard weight, within the limits of which a comparison stimulus, although physically lighter or heavier than the standard weight, will not be judged lighter or heavier with a probability of 0.50. This distance is called the interval of uncertainty and is defined as the difference between the two thresholds. The measure of sensitivity is one half this interval. For example, if we have a standard weight of 100 grams and our interval of uncertainty is 4 grams, the measure of sensitivity will be 2 grams. This means that either a weight of 102 or of 98 grams will be distinguished from a weight of 100 grams with a probability of 0.50.

But these are not all the considerations that are necessary to tell the sensitivity of our subject. It will be remembered that our results are effected by constant errors. Two weights of 100 grams if lifted in either different spacial or temporal relations will not be subjectively equal. In our experiments the space error was eliminated by the turning top table, but the time error was present, although it was controlled by the regular beats of the metronome. We must now find the point of subjective equality, which is that weight which, under the conditions of our experimental procedure, will be subjectively equal to our standard weight. This is found by applying the formula

$$\xi = \frac{c_1 + c_2}{h_1 + h_2} .$$

When this point of subjective equality has been ascertained, we can find the influence of the constant errors almost directly, by finding the difference between the point of subjective equality and the standard stimulus. We will consider how this effects our example given above. Suppose we find that the influence of the time error is — 3 grams. In this case our point of subjective equality is 97 grams. The measure of sensitivity remains the same, however. Thus a restatement of our results indicates that without the influence of the time error, weights of 95 or 99 grams can be distinguished from one of 97 grams.

Table XIII is a double table containing the values for our subjects of these quantities we have just discussed. For each subject will be found in order the values of the interval of uncertainty; the point of subjective equality; and the time error. These will be found opposite the number of each of the groups of 100 experiments into which our results were divided. At the bottom will be found the averages for each of the columns.

It will be noticed that the interval of uncertainty remains very constant for both subjects although the values are by no means identical. The variations are obviously due to changes in the sensitivity of the subject. These are the changes that are caused by the variations in the psychophysical makeup of the individual. There does not seem to be any correlation between the character of these changes for the two subjects. We see that the averages of the interval of uncertainty are almost identical for the two subjects. This is of course a matter of chance and merely indicates that the sensitivity of the two subjects happened to be almost the same.

The time error was a negative one in the Fechnerian sense; that is, the second weight lifted was relatively heavier. This means that the point of subjective equality is smaller than the standard weight. Thus, on the average, for subject I for our arrangement of the experiment, a standard weight of 100 grams would be subjectively equal to a comparison weight of 97.31 grams. It will be noticed that the point of subjective equality is practically midway between the two thresholds. This indicates that the amount that must be added in order to perceive a difference between the two weights is approximately the same as the amount that must be subtracted in order to just perceive a difference. For our calculations the point of subjective equality remained comparatively constant for each subject, but there is considerable difference [one gram on the average] for the two subjects. The time error for subject I seems to become less as the experiment

| | Subject I | | | Subject II | | |
|---|---|---|---|---|---|---|
| Number of Groups | Interval of Uncertainty | Point of Subjective Equality | Time Error | Interval of Uncertainty | Point of Subjective Equality | Time Error |
| I | 5.49 | 96.83 | — 3.17 | 4.90 | 95.30 | — 4.70 |
| II | 5.92 | 96.97 | — 3.03 | 4.80 | 97.09 | — 2.91 |
| III | 4.98 | 96.76 | — 3.24 | 3.23 | 96.80 | — 3.20 |
| IV | 4.85 | 97.64 | — 2.36 | 3.70 | 96.17 | — 3.83 |
| V | 5.52 | 96.76 | — 3.24 | 3.18 | 96.24 | — 3.76 |
| VI | 5.42 | 96.87 | — 3.13 | 4.28 | 95.72 | — 4.28 |
| VII | 4.83 | 97.34 | — 2.66 | 4.98 | 96.29 | — 3.71 |
| VIII | 4.42 | 97.12 | — 2.88 | 5.70 | 95.42 | — 4.58 |
| IX | 4.26 | 97.21 | — 2.79 | 5.47 | 95.50 | — 4.50 |
| X | 3.84 | 98.06 | — 1.94 | 4.80 | 96.16 | — 3.84 |
| XI | 5.52 | 97.47 | — 2.53 | 5.72 | 95.67 | — 4.33 |
| XII | 5.08 | 97.49 | — 2.51 | 5.84 | 97.62 | — 2.38 |
| XIII | 4.80 | 98.32 | — 1.68 | 6.13 | 96.95 | — 3.05 |
| XIV | 5.48 | 97.50 | — 2.50 | 5.25 | 97.43 | — 2.57 |
| Average | 5.03 | 97.31 | — 2.69 | 4.86 | 96.31 | — 3.69 |

TABLE XIII

proceeds. The physical conditions remained the same throughout the experiment as this constancy is attested by the fact that there are no systematic variations in the course of the time error for subject II. This systematic change, found in the results of subject I is not very great and thus may be due to the chance arrangement of the results. If it is significant, however, it must be due to some change in the psychophysical organism. It is not due to an effect of practice, since on the basis of the discussion of practice given above, we should expect to find an even stronger tendency in subject II, where it is entirely absent.

## IV. METHOD OF JUST PERCEPTIBLE DIFFERENCES

The classical form of procedure of the method of just perceptible differences is to start with two stimuli at subjective equality and increase the comparison stimulus C by equal steps only up to the point where a difference is first noticed; this point we call the just perceptible positive difference. We then start again, to obtain the just imperceptible positive difference, with the comparison stimulus C subjectively greater than the standard stimulus S; then C is decreased until no difference is perceived between C and S. Again we start with C and S subjectively equal and decrease C until it is first judged less and thus obtain the just perceptible negative difference. Finally, to obtain the just imperceptible negative difference, we start with C subjectively less than S and increase C to the point where it is first impossible to perceive a difference. Then the just perceptible and imperceptible positive differences are averaged and we obtain the threshold in the direction of increase. The threshold in the direction of decrease is found by averaging the just perceptible and imperceptible negative differences. This is the form in which this method was described by Fechner [*Elemente der Psychophysik,* I, p. 72], Wundt [*Phys. Psych.,* I, 1902, p. 475], Müller [*Gesichtspunkt und die Tatschen der psychophysischen Methodik,* 1904, p. 179], and Titchener [*Exp. Psych.* II, I, p. 56].

Another form of the method of just perceptible differences is the one used in this experiment, which decreases the amount of experimentation considerably and has also other advantages. We start with C so much lighter than S that there is a very small probability of any but a lighter judgment, and then increase the comparison stimulus C by successive steps until there is a very small probability of any but a heavier judgment. The four differences, from which the thresholds are obtained, are then picked out of the results and are defined in the following manner. The just perceptible negative difference is the greatest stimulus upon which a lesser judgment is passed. The just imperceptible negative difference is the smallest stimulus upon which a not-lighter—either equal or heavier—judgment is given. The smallest stimulus upon which a heavier judgment is given becomes the just perceptible positive difference. Finally, the greatest stimulus upon which a not-greater—equal or less—judgment is passed is the just imperceptible positive difference. Thus in one experimental operation we obtain all the values that in the other form of the method required four distinct series. After these differences are obtained, the thresholds are found in the same manner as in the other method. Besides the matter of expediency, there is another great advantage of this form of the method over the classical form. The original method requires that we start at the point of subjective equality; but this term is not defined and the method gives no indication as to what intensity of the comparison stimulus is to be used for it. In actual practice this method is handled in such a way that the comparison stimulus is used, as a starting point, on which an equality judgment is given. This definition, however, is very loose since a great number of comparison stimuli fulfill this requirement. The variation of the method now under consideration, avoids this disadvantage by not making use of the notion of subjective equality at all. The fact that this variation gives satisfactory results indicates clearly that only the so-called upper and lower limits of the interval of uncertainty are of consequence for the determination of the sensitivity of the subject. From this it seems to follow that the discussion as to whether the arithmetic mean or the geometric mean ought to be taken as representative of the point of subjective equality, cannot be decided on the ground of this method; since it does not give any definition of that value whatsoever. [Wundt, *Phys. Psych.,* I, 5th Ed., p. 477.]

In order to avoid the so-called errors of expectation, a descending series of just the reverse experimental procedure was taken for every ascending series, of the form that has been described. This influence of expectation may be twofold; either, if the subject knows that he is in an ascending series, he may give a heavier judgment too soon, or that knowledge may bias him against giving such a judgment. Similarly he may give a lighter judgment too soon or not soon enough, if the subject knows that he is in a descending series. There is, however, a great difference of opinion as to the extent of the influence of expectation. For example, Wundt [*Phys. Psych.,* I, 1902, p. 479, 491] believes that this tendency may be overcome by practice; and Fullerton and Cattell [*Small differences*] think that this influence is so great that they strongly recommend that the subject should have no knowledge of the type of series that he is judging. In many cases it is not possible to keep this knowledge from the subject. For example, in the present study, the subject could tell from the sound made by the bearings being placed in the cylinder, whether he was judging an ascending or descending series. In the old form of the experimental procedure of this method, it was not possible to keep this knowledge from the subject because, after the first judgment, he could realize which type of series he was judging. On the other hand, Titchener [*Exp. Psych.* II, II, p. 128] states that with good subjects this expectation has no influence whatsoever. Whether this is true or not, the method of double procedure, used in this study, allows for this error if present. Since it is not possible to avoid this error, one tried to eliminate it, or at least, to minimize its influence by using ascending and descending series alternately. The errors being in opposite direction in the series may be expected to cancel one another.

We will now analyze the nature of the four differences upon which this method is based. It was believed for a long time, that the method of just perceptible differences uses notions which are foreign to the error methods. Urban, however, has shown that the common source of both methods is to be found in the notion of the probability of a certain judgment. The just perceptible negative difference may be defined as the largest stimulus on which a lighter judgment was given. This implies that none of the greater comparison stimuli were judged lighter, but that on this one a lighter judgment was given. Thus by definition of the other differences, the just imperceptible negative difference implies that all the smaller stimuli were judged lighter but this one was judged not-lighter. The just perceptible positive difference implies that all smaller stimuli were judged not-heavier while on this one a heavier judgment was passed. Finally the just imperceptible positive difference implies that, on all greater stimuli, a heavier judgment was passed but on this one a not-heavier. Now let q be the probability of a lighter judgment on a given intensity of the comparison stimulus. Then by definition, the probability of a not-lighter judgment will be 1 — q, as these probabilities are mutually exclusive. In this same way 1 — p will be the probability of a not-heavier judgment, if the probability of a heavier judgment is p Now suppose we have a series of comparison stimuli $r_1$, $r_2$, . . . $r_n$ arranged in the order of their intensity, in which $r_1$ is the heaviest, and we use this series for the determination of the just perceptible negative difference. Let us designate the probabilities of a lighter judgment on the first, second, . . . n comparison stimuli by $q_1$, $q_2$, . . . $q_n$. There exists for each stimulus a certain probability that it will be obtained as a determination of the just perceptible negative difference, which we call $Q_1$, $Q_2$, . . . $Q_n$ .

$$Q_1 = q_1 \;;$$
$$Q_2 = (1-q_1)q_2 \;;$$
$$Q_{n-1} = (1-q_1)(1-q_2) \cdots\cdots (1-q_{n-2})q_{n\;1} \;;$$
$$Q_n = (1-q_1)(1-q_2) \cdots\cdots (1-q_{n-1})q_n \;.$$

The probability that a stimulus will be obtained as a determination of the just imperceptible negative difference can be similarly analyzed. For the comparison stimuli $r_1, r_2 \ldots r_n$ we have

$$Q_1^1 = q_n \cdot q_{n-1} \cdot \cdots \cdots q_2 (1 - q_1) \;;$$
$$Q_2^1 = q_n \cdot q_{n-1} \cdot \cdots \cdots q_3 (1 - q_2) \;;$$
$$Q_{n-1}^1 = q_n (1 - q_{n-1}) \;;$$
$$Q_n^1 = (1 - q_{n-1}) \;.$$

The probabilities that the just perceptible positive difference will fall on the stimuli $r_1, r_2, \ldots r_n$ are expressed

$$P_1 = (1 - p_n)(1 - p_{n-1}) \cdots \cdots (1 - p_2) p_1 \;;$$
$$P_2 = (1 - p_n)(1 - p_{n-1}) \cdots \cdots (1 - p_3) p_2 \;;$$
$$P_{n-1} = (1 - p_n) p_{n-1} \;;$$
$$P_n = p_n \;.$$

Finally the probabilities with which the different stimuli will be obtained as a determination of the just imperceptible positive difference for the stimuli $r_1, r_2, \ldots r_n$ are

$$P_1^1 = (1 - p_1) \;;$$
$$P_2^1 = p_1 (1 - p_2) \;;$$
$$P_{n-1}^1 = p_1 \cdot p_2 \cdot \cdots \cdots p_{n-2} (1 - p_{n-1}) \;;$$
$$P_n^1 = p_1 \cdot p_2 \cdot \cdots \cdots p_{n-1} (1 - p_n) \;.$$

We now turn to a discussion of the results of our experiments. It will be remembered that one of the comparison stimuli was changed systematically so that the results on it could serve as a determination of the thresholds of the method of just perceptible differences, and at the same time, the judgments on the other comparison stimuli enabled us to apply the method of constant stimuli; the relation of these two methods being the principal problem of this paper. Obviously there is no difference in the form of the individual judgments of these two methods, since they consist in the passing of a judgment of whether the comparison stimulus is subjectively lighter, equal or heavier than the standard stimulus. Our results of the method of just perceptible differences are of two forms; observed values that were taken simultaneously with those by the method of constant stimuli, and calculated values. One way of obtaining these calculated values

| | I | II | III | IV | V | VI | VII | VIII | IX | X | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 84.80 | | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 100 |
| 85.22 | | | | | | | | | | | 10 |
| 85.64 | | 10 | | | | | | | | | 10 |
| 86.06 | | | 10 | 10 | | | | | | | 20 |
| 86.48 | | 10 | | | 10 | | | | | | 10 |
| 86.90 | | | | | | 10 | | | | | 30 |
| 87.32 | | 10 | 10 | | | | 10 | | | | 20 |
| 87.74 | 10 | | | 10 | | | | 10 | | | 30 |
| 88.16 | | 10 | | | | | | | 10 | | 20 |
| 88.58 | | | | | | 10 | | | | 10 | 30 |
| 89.00 | | 10 | | 10 | | 10 | | | | | 40 |
| 89.84 | | 10 | 10 | | | | | | | | 10 |
| 90.26 | 10 | | | | | | 10 | | | | 20 |
| 90.68 | | 10 | | | 10 | | | | | | 20 |
| 91.10 | | | 10 | 10 | | | | 10 | | | 30 |
| 91.52 | | 10 | | | | 10 | | | 10 | | 50 |
| 92.36 | 10 | 10 | 10 | 10 | 10 | | | | | 10 | 40 |
| 93.20 | | 10 | | | | | 10 | | | | 20 |
| 93.62 | | | 10 | | | | | | | | 20 |
| 94.04 | 10 | 10 | | 10 | | 10 | | 10 | | | 50 |
| 94.88 | | 10 | 10 | | 10 | | | | | | 20 |
| 95.30 | 10 | | | | | | | | | | 10 |
| 95.72 | | 10 | | | | | | | 10 | | 30 |
| 96.14 | 10 | | 10 | 10 | | | 10 | | | | 40 |
| 96.56 | 10 | 10 | | | | | | | | | 10 |
| 96.98 | 10 | | | | 10 | 10 | | | | 10 | 60 |
| 97.40 | 10 | 10 | | | | | | | | | 10 |
| 97.82 | 10 | | | 10 | | | | 10 | | | 40 |
| 98.24 | 10 | 10 | | | | | | | | | 20 |
| 98.66 | 10 | | 10 | | | | | | | | 10 |
| 99.08 | | 10 | | | 10 | | 10 | | | | 30 |
| 99.50 | 10 | | | 10 | | 10 | | | 10 | | 50 |
| 99.92 | | 10 | 10 | | | | | | | | 20 |
| 100.76 | 10 | 10 | | | | | | | | | 10 |
| 101.18 | | | | 10 | 10 | | | 10 | | 10 | 50 |
| 101.60 | | 10 | | | | 10 | 10 | | | | 50 |
| 102.44 | 10 | 10 | 10 | 10 | | | | | | | 20 |
| 103.28 | | 10 | | | 10 | | | | 10 | | 30 |
| 103.70 | | | 10 | | | | | | | | 10 |
| 104.12 | | 10 | | | | | | | | | 10 |
| 104.54 | 10 | | | 10 | | 10 | | 10 | | | 50 |
| 104.96 | | 10 | 10 | | | | 10 | | | | 10 |
| 105.38 | | | | | 10 | | | | | 10 | 30 |
| 105.80 | | 10 | | | | | | | | | 10 |
| 106.22 | | | 10 | 10 | | | | | | | 20 |
| 106.64 | | 10 | | | | | | | | | 10 |
| 107.06 | 10 | | | | | 10 | | | 10 | | 40 |
| 107.48 | | 10 | 10 | | 10 | | 10 | | | | 10 |
| 107.90 | | | | 10 | | | | 10 | | | 40 |
| 108.32 | | 10 | | | | | | | | | 10 |
| 108.74 | | | 10 | | | | | | | | |
| 110.00 | 10 | | | | | 10 | | | | 10 | 30 |
| 111.26 | | | | | | | 10 | | 10 | | 20 |
| 112.52 | | | | | | 10 | | | | | 10 |

is that employed by Urban [*Stat. Meth.*], where the experimental data were in such a form that it was possible to apply both forms of mathematical treatment to the same set of results. This is not possible in the present study as a glance at the table below will convince one that not enough judgments were taken on each intensity of the comparison stimulus to enable us to apply the treatment of the method of constant stimuli. In this table are found the number of judgments passed on the intensities of the comparison stimulus for each series, and the last column gives the totals for each intensity used.

The other way of approaching this problem is to take the results of the method of constant stimuli and calculate from them the results we are likely to obtain from the method of just perceptible differences. This is possible because the determination of the quantities h and c determines the entire course of the psychometric functions. We, therefore, are able to obtain the probabilities of all three judgments on any comparison stimulus, if the constants h and c for the lighter and heavier judgments are given. These probabiltiies are indeed, all that we need for the calculation of the method of just perceptible differences, and we therefore can find the most probable value of any one of the four differences. The conditions under which our results for the methods of just perceptible differences and constant stimuli were taken, were very much the same, if not entirely alike, and we therefore, may expect to obtain calculated results which agree with the observed results within the limits of accuracy obtainable in this kind of experiments. The calculation of the probabilities with which the different intensities of the comparison stimulus will be obtained as determinations of the different perceptible and imperceptible positive and negative differences is easy but rather long and somewhat complicated. So it is necessary to plan the whole work systematically in a manner which will now be described.

The first step consisted in the collection of the material for the determination of the constants of the psychometric functions. The records, as they were taken during experimentation, were entered in tables, similar in form to those described above as the records of first entry, but the records of each series of the method of just perceptible differences were kept separate. The relative frequencies of the judgments in this division of the results by series, are found in tables XIV and XV for subjects I and II respectively. These are similar in form to tables III and IV, with the exception that the numbers in the first column, instead of representing groups of 100 judgments, as in the former calculation, now indicate the series of the method of just perceptible differences with which they were taken simultaneously. As has been pointed out above, the length of the different series of the method of just perceptible differences varied; there being only seven judgments for series X; while series II required the passing of twenty-nine judgments. Thus it is obvious that the number of judgments from which these relative frequencies were calculated vary in a similar ratio.

From these relative frequencies, the constants for the method of constant stimuli, h and c, were calculated by the same method that has been described above. In order to show the steps of this calculation, tables XVI and XVII give, for the lighter and heavier judgments of subject I, the values of [P], [xP], [xxP], [$\gamma$P], [x$\gamma$P], [sP] and [xsP]. The corresponding values are found for subject II in tables XVIII and XIX. These four tables are similar in form to tables VII-X, which have been described above. The numbers in the first five columns give the coefficients for setting up the normal equations and the data of the columns [sP] and [xsP] show that all the necessary checks are fulfilled. Tables XX and XXI, which are similar in form to tables XI and XII, give the constants h and c for the lighter and heavier judgments for both subjects. The thresholds $S_1$ and $S_2$ are obtained in the same way as in the former calculation and are included in these tables. The series of the method of just perceptible differences were performed in haphazard order, so that the results that go to make up the values included in these tables, are from various parts of the experiment at different stages of practice, and we, therefore, must not look for the effect of practice in these constants. In fact the results that were taken at the end of the experiment in each series, where the practice was high, tend to cancel any

| | 84 | | | 88 | | | 92 | | | 96 | | | 104 | | | 108 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Series | Lighter | Equal | Heavier | Lighter | Equal | Heavier | Lighter | Equal | Heavier | Lighter | Equal | Heavier | Lighter | Equal | Heavier | Lighter | Equal | Heavier |
| I......... | .963 | .032 | .005 | .895 | .105 | .000 | .626 | .263 | .111 | .458 | .363 | .179 | .063 | .158 | .779 | .032 | .063 | .905 |
| II......... | .966 | .034 | .000 | .876 | .114 | .010 | .659 | .210 | .131 | .441 | .359 | .200 | .072 | .152 | .776 | .024 | .055 | .921 |
| III......... | .960 | .040 | .000 | .880 | .100 | .020 | .600 | .275 | .125 | .405 | .400 | .195 | .085 | .140 | .775 | .010 | .060 | .930 |
| IV......... | .973 | .020 | .007 | .907 | .073 | .020 | .667 | .220 | .113 | .353 | .407 | .240 | .087 | .226 | .687 | .013 | .073 | .914 |
| V......... | .950 | .042 | .008 | .867 | .100 | .033 | .675 | .250 | .075 | .350 | .367 | .283 | .050 | .175 | .775 | .000 | .042 | .958 |
| VI......... | .983 | .017 | .000 | .833 | .150 | .017 | .583 | .300 | .117 | .467 | .333 | .200 | .075 | .133 | .792 | .008 | .083 | .908 |
| VII......... | .930 | .050 | .020 | .850 | .140 | .010 | .650 | .210 | .140 | .410 | .440 | .150 | .020 | .110 | .870 | .010 | .050 | .940 |
| VIII......... | .988 | .012 | .000 | .825 | .125 | .050 | .650 | .250 | .100 | .500 | .338 | .162 | .038 | .150 | .812 | .012 | .038 | .950 |
| IX......... | .988 | .012 | .000 | .875 | .125 | .000 | .737 | .200 | .063 | .375 | .350 | .275 | .038 | .162 | .800 | .012 | .088 | .900 |
| X......... | .971 | .029 | .000 | .886 | .114 | .000 | .600 | .314 | .086 | .286 | .443 | .271 | .057 | .114 | .829 | .014 | .000 | .986 |

TABLE XIV

| | 84 | | | 88 | | | 92 | | | 96 | | | 104 | | | 108 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Series | Lighter | Equal | Heavier | Lighter | Equal | Heavier | Lighter | Equal | Heavier | Lighter | Equal | Heavier | Lighter | Equal | Heavier | Lighter | Equal | Heavier |
| I......... | .989 | .011 | .000 | .795 | .173 | .032 | .579 | .295 | .126 | .257 | .417 | .326 | .058 | .163 | .799 | .016 | .042 | .942 |
| II......... | .962 | .035 | .003 | .859 | .100 | .041 | .607 | .245 | .148 | .417 | .269 | .314 | .048 | .155 | .797 | .026 | .059 | .915 |
| III......... | .955 | .025 | .020 | .860 | .120 | .020 | .585 | .225 | .190 | .385 | .270 | .345 | .070 | .125 | .805 | .000 | .040 | .960 |
| IV......... | .973 | .020 | .007 | .753 | .167 | .080 | .640 | .213 | .147 | .380 | .287 | .330 | .033 | .120 | .847 | .020 | .060 | .920 |
| V......... | .925 | .050 | .025 | .775 | .200 | .025 | .575 | .333 | .092 | .375 | .342 | .283 | .033 | .134 | .833 | .008 | .050 | .942 |
| VI......... | .917 | .067 | .016 | .800 | .183 | .017 | .533 | .225 | .242 | .358 | .308 | .334 | .058 | .100 | .842 | .025 | .092 | .883 |
| VII......... | .960 | .030 | .010 | .900 | .080 | .020 | .610 | .280 | .110 | .340 | .350 | .310 | .030 | .100 | .870 | .010 | .090 | .900 |
| VIII......... | .963 | .037 | .000 | .865 | .085 | .050 | .600 | .225 | .175 | .375 | .412 | .213 | .075 | .125 | .800 | .012 | .050 | .938 |
| IX......... | .962 | .025 | .013 | .900 | .075 | .025 | .600 | .288 | .112 | .400 | .362 | .238 | .025 | .075 | .900 | .013 | .012 | .975 |
| X......... | .986 | .014 | .000 | .886 | .071 | .043 | .614 | .243 | .143 | .414 | .286 | .300 | .014 | .172 | .814 | .029 | .071 | .900 |

TABLE XV

| Series | [P] | [xP] | [xxP] | [γP] | [γxP] | [sP] | [sxP] |
|---|---|---|---|---|---|---|---|
| I | 3.467 | 327.50 | 31083.04 | — 0.215 | — 3.890 | 324.244 | 30759.43 |
| II | 3.263 | 308.27 | 29264.83 | — 0.201 | — 3.053 | 305.210 | 28959.61 |
| III | 3.456 | 324.72 | 30639.88 | — 0.220 | — 5.965 | 321.480 | 30321.13 |
| IV | 3.260 | 307.92 | 29209.52 | — 0.138 | 1.943 | 304.802 | 28899.65 |
| V | 3.207 | 297.73 | 27736.32 | — 0.534 | —37.912 | 295.055 | 27476.50 |
| VI | 3.196 | 298.37 | 27946.14 | — 0.406 | —27.664 | 295.578 | 27675.41 |
| VII | 3.332 | 308.34 | 28643.10 | — 0.590 | —41.793 | 305.602 | 28376.55 |
| VIII | 3.152 | 295.88 | 27873.49 | — 0.325 | —18.834 | 293.057 | 27596.44 |
| IX | 2.981 | 280.20 | 26434.32 | — 0.297 | —15.127 | 277.520 | 26169.24 |
| X | 3.213 | 301.77 | 28461.02 | 0.012 | 15.857 | 298.543 | 28143.40 |

Table XVI

| Series | [P] | [xP] | [xxP] | [γP] | [xγP] | [sP] | [sxP] |
|---|---|---|---|---|---|---|---|
| I | 2.683 | 267.31 | 26741.18 | — 0.152 | — 2.078 | 264.781 | 26475.95 |
| II | 2.782 | 275.77 | 27445.62 | — 0.235 | —10.051 | 273.225 | 27179.89 |
| III | 2.801 | 276.67 | 27442.42 | — 0.342 | —19.806 | 274.209 | 27185.55 |
| IV | 3.081 | 304.28 | 30189.97 | — 0.524 | —36.269 | 301.727 | 29921.95 |
| V | 2.820 | 275.94 | 27126.43 | — 0.505 | —33.952 | 273.629 | 26884.42 |
| VI | 2.773 | 275.27 | 27437.04 | — 0.228 | — 8.872 | 272.723 | 27170.64 |
| VII | 2.632 | 256.67 | 25164.94 | — 0.510 | —33.105 | 254.546 | 24941.38 |
| VIII | 2.688 | 263.29 | 25908.38 | — 0.506 | —34.691 | 261.106 | 25679.78 |
| IX | 2.593 | 259.91 | 26139.30 | 0.133 | 24.084 | 257.186 | 25855.30 |
| X | 2.108 | 208.28 | 20634.69 | — 0.038 | 4.275 | 206.210 | 20422.13 |

Table XVII

| Series | [P] | [xP] | [xxP] | [γP] | [γxP] | [sP] | [sxP] |
|---|---|---|---|---|---|---|---|
| I......... | 3.279 | 308.18 | 29080.22 | 0.281 | 39.716 | 304.616 | 28732.33 |
| II......... | 3.477 | 326.78 | 30852.98 | — 0.178 | — 0.928 | 323.481 | 30527.12 |
| III......... | 3.362 | 313.20 | 29281.58 | — 0.382 | —23.776 | 310.216 | 28992.16 |
| IV......... | 3.446 | 321.88 | 30188.08 | — 0.137 | 0.914 | 318.567 | 29865.29 |
| V......... | 3.570 | 330.05 | 30631.86 | — 0.310 | —15.647 | 326.792 | 30317.45 |
| VI......... | 3.807 | 355.25 | 33313.87 | — 0.010 | 15.666 | 351.455 | 32942.95 |
| VII......... | 3.115 | 290.54 | 27200.90 | — 0.266 | —11.524 | 287.687 | 26921.89 |
| VIII......... | 3.443 | 323.25 | 30477.95 | — 0.151 | 0.699 | 319.956 | 30154.00 |
| IX......... | 3.138 | 292.88 | 27439.57 | — 0.338 | —18.450 | 290.084 | 27165.13 |
| X......... | 3.058 | 287.41 | 27117.62 | — 0.214 | — 7.486 | 284.568 | 26837.62 |

TABLE XVIII

| Series | [P] | [xP] | [xxP] | [γP] | [γxP] | [sP] | [sxP] |
|---|---|---|---|---|---|---|---|
| I......... | 2.988 | 293.38 | 28924.10 | — 0.267 | —12.282 | 290.655 | 28642.99 |
| II......... | 3.190 | 312.77 | 30807.74 | — 0.322 | —15.760 | 309.900 | 30510.74 |
| III......... | 3.134 | 303.85 | 29600.05 | — 0.437 | —26.432 | 301.155 | 29322.63 |
| IV......... | 3.293 | 319.85 | 31225.86 | — 0.427 | —24.070 | 316.982 | 30930.08 |
| V......... | 2.928 | 284.98 | 27886.22 | — 0.534 | —34.247 | 282.586 | 27635.47 |
| VI......... | 3.366 | 329.17 | 32354.14 | — 0.200 | — 2.893 | 326.002 | 32027.87 |
| VII......... | 2.939 | 288.46 | 28452.88 | — 0.286 | —11.280 | 285.807 | 28175.70 |
| VIII......... | 3.041 | 297.24 | 29185.01 | — 0.435 | —27.659 | 294.630 | 28915.43 |
| IX......... | 2.511 | 242.32 | 23492.45 | — 0.637 | —46.675 | 240.446 | 23296.80 |
| X......... | 3.157 | 310.32 | 30643.18 | — 0.257 | —10.028 | 307.424 | 30342.88 |

TABLE XIX

*Subject I*

| Series | Lighter Judgments | | | Heavier Judgments | | |
|---|---|---|---|---|---|---|
| | $h_1$ | $c_1$ | $S_1$ | $h_2$ | $c_2$ | $S_2$ |
| I | 0.11214 | 10.655 | 95.02 | 0.12064 | 12.076 | 100.10 |
| II | 0.11266 | 10.705 | 95.02 | 0.12071 | 12.050 | 99.82 |
| III | 0.11354 | 10.732 | 94.52 | 0.12315 | 12.287 | 99.77 |
| IV | 0.11883 | 11.266 | 94.81 | 0.11088 | 11.121 | 100.30 |
| V | 0.12186 | 11.480 | 94.20 | 0.12373 | 12.286 | 99.30 |
| VI | 0.11265 | 10.644 | 94.48 | 0.12340 | 12.332 | 99.93 |
| VII | 0.11650 | 10.958 | 94.06 | 0.12359 | 12.246 | 99.09 |
| VIII | 0.11833 | 11.211 | 94.74 | 0.12528 | 12.459 | 99.45 |
| IX | 0.13213 | 12.519 | 94.75 | 0.12345 | 12.323 | 99.82 |
| X | 0.12429 | 11.670 | 93.89 | 0.14430 | 14.276 | 98.93 |

TABLE XX

*Subject II*

| Series | Lighter Judgments | | | Heavier Judgments | | |
|---|---|---|---|---|---|---|
| | $h_1$ | $c_1$ | $S_1$ | $h_2$ | $c_2$ | $S_2$ |
| I | 0.11824 | 11.027 | 93.26 | 0.11783 | 11.659 | 98.94 |
| II | 0.11210 | 10.587 | 94.44 | 0.11134 | 11.018 | 98.96 |
| III | 0.11295 | 10.636 | 94.16 | 0.11297 | 11.092 | 98.19 |
| IV | 0.11189 | 10.491 | 93.76 | 0.10936 | 10.752 | 98.32 |
| V | 0.11007 | 10.263 | 93.24 | 0.11875 | 11.740 | 98.86 |
| VI | 0.10147 | 9.472 | 93.34 | 0.10204 | 10.038 | 98.37 |
| VII | 0.13067 | 12.273 | 93.93 | 0.11900 | 11.777 | 98.96 |
| VIII | 0.11490 | 10.831 | 94.27 | 0.11320 | 11.208 | 99.00 |
| IX | 0.12538 | 11.810 | 94.20 | 0.13827 | 13.597 | 98.34 |
| X | 0.12024 | 11.371 | 94.57 | 0.10909 | 10.805 | 99.04 |

TABLE XXI

variation of the results at the beginning, where practice was low. Thus these values of the threshold show remarkably little variation. The numbers under the headings $S_1$ and $S_2$ give the thresholds in the direction of increase and decrease by the method of constant stimuli, for the group of experiments that were made simultaneously with the corresponding series of the method of just perceptible differences.

After having obtained the constants h and c, we can ascertain the probability of a heavier or lighter judgment for any intensity of the comparison stimulus, by the formula

$$p = \frac{1}{2} \pm \frac{1}{2} \Phi(\gamma) .$$

This calculation is made in two steps; as first $\gamma$ must be calculated by the formula

$$\gamma = hx - c$$

in which x is the value of the intensity of the stimulus for which we are calculating the probability. The value of $\Phi(\gamma)$ is then looked in a table of the probability integral [Czuber. *Wahr-*

*scheinlichkeitsrechnung,* 1908, pp. 388-391]. This value of $\Phi(\gamma)$, which takes the sign of its argument, is substituted in the formula given above and we obtain the probability of that judgment for the weight x. These values must be found for every intensity of the comparison stimulus that was used in the corresponding series for the method of just perceptible differences.

In actual practice this calculation is very much simplified. If we desire the probabilities of the lighter judgments q, for series II, we first find $\gamma_1$ for $x = 84.80$, this being our lightest comparison weight. We then find the value of $\gamma$ for x equal to the amount of difference of the steps of this series. This value is subtracted from $\gamma_1$ and we obtain $\gamma_2$ or that of the next heavier comparison stimulus. Then $\gamma$ is subtracted from $\gamma_2$ and we obtain $\gamma_3$ for the next heavier comparison weight, and so forth. As our $\gamma$ values are only carried out to four places, corrections have to be made when necessary. A check on this step of the calculations is effected by finding the $\gamma$ of the heaviest comparison weight by means of the formula, and ascertaining if it coincides with the value obtained by the series of subtractions. These $\gamma$'s are then successively introduced into the formula for finding the probabilities, given above, and the different probabilities of the lighter judgment — q — are obtained for all of the comparison stimuli used. The probabilities that a not-lighter—equal or heavier—judgment will be passed are obtained by subtracting the probabilities of a lighter judgment, in each case, from unity.

From this series of the q's and (I — q)'s we may obtain the just perceptible negative difference and the just imperceptible negative difference, by means of the formulae given above. This calculation is much simplified by the use of logarithms. These are looked up for every value of q and 1 — q. Then the probability that our lightest weight will be obtained as a determination of the just imperceptible negative difference is $Q_1 = (1 - q_1)$ and is found directly. Adding log $q_1$ to log $(1 - q_2)$ gives log $Q_2$ which is the probability that our next heavier comparison stimulus will be obtained as a determination of this difference. Then log $q_1$ is added to log $q_2$ and to their sum is added log $(1 - q_3)$ which gives $Q_3$. To the sum of log $q_1$ and $q_2$ is added log $q_3$ and to this sum is added log $(1 - q_4)$, which gives the probability that this difference will fall on the fourth comparison weight. This scheme of calculation is very simple and is learned rapidly; its mechanism will be easily understood from the following example, where the formulae are found alongside part of one of our calculations.

$$
\begin{array}{lll}
\log Q_1 = & \log q_1 & = .94448 - 3 \\
 & \log (1-q_1) & = .99616 - 1 \\
 & \log (q_2) & = .44716 - 2 \\
\cline{2-3}
\log Q_2 = & \log (1-q_1)\ q_2 & = .44332 - 2 \\
 & \log (1-q_1) & = .99616 - 1 \\
 & \log (1-q_2) & = .98767 - 1 \\
\cline{2-3}
 & \log (1-q_1)(1-q_2) & = .98383 - 1 \\
 & \log q_3 & = .81558 - 2 \\
\cline{2-3}
\log Q_3 = & \log (1-q_1)(1-q_2)\ q_3 & = .79941 - 2 \\
 & \log (1-q_1)(1-q_2) & = .98383 - 1 \\
 & \log (1-q_3) & = .97063 - 1 \\
\cline{2-3}
 & \log (1-q_1)(1-q_2)(1-q_3) & = .95446 - 1 \\
 & \log q_4 & = .07700 - 1 \\
\cline{2-3}
\log Q_4 = & \log (1-q_1)(1-q_2)(1-q_3)\ q_4 & = .03146 - 1 \\
 & \vdots & \vdots
\end{array}
$$

In this way the calculation is reduced to a number of successive additions by carrying the sums of the terms that accumulate. These additions give us the values of Q and $Q_1$, or the probabilities with which the just perceptible and imperceptible negative differences will fall on the different values of the comparison stimulus. A similar calculation with the h and c for the heavier judgments gives the values of P and $P_1$, or the probabilities that the different intensities of the comparison stimulus will be found as a determination of the just perceptible and imperceptible positive differences. Both sets of calculations for the heavier and lighter judgments, had to be performed for each of the ten series for both subjects.

A check on this part of the calculations is effected by the fact that, as these are probabilities of mutually exclusive events, all the values in one set must add up to unity. This had to prove within a limit of 0.0001, which was the exactitude of our calculations. It was found for the longer series that this calculation did not have to be carried through for all of the values of x, as frequently the probabilities of the differences became so small as to no longer affect the last decimal place. In the short series, on the other hand, it frequently happened that there was a remainder, and this had to be calculated as it was necessary for a check of the correctness of our work. This remainder has some significance since it gives the probability that the series of comparison stimuli $r_1, r_2, \ldots r_n$ will be gone through without giving a determination of the quantity sought for. Thus the remainder for the just perceptible positive difference gives the probability that no stimulus of the series will be obtained as a determination of this quantity or—what is the same—that no heavier judgment will be given on any of the stimuli used. This remainder has the form of a product of probabilities and obviously becomes very small if any factors are small. Thus in our short series there was greater likelihood of having larger individual probabilities and we find a tendency for greater remainders to occur in the short series rather than in the long ones. This is the reason of the rule that the series of comparison stimuli should be extended so far that we will have a very high probability of obtaining only heavier judgments on the largest comparison stimulus, and only lighter judgments on the smallest stimulus used. It is, therefore, not desirable to work with series in which the remainders are of at all considerable size. None of the remainders of our series are large enough to invalidate our results in any way.

Tables XXII-XXXI give the results of these calculations for

*Series I*

| Comparison Stimulus | q | Q | Q¹ | p | P | P¹ |
|---|---|---|---|---|---|---|
| 84.80 | 0.947 | 0.0001 | 0.0526 | 0.005 | 0.0046 | |
| 87.74 | 0.876 | 0.0003 | 0.1177 | 0.018 | 0.0174 | |
| 90.26 | 0.774 | 0.0014 | 0.1871 | 0.047 | 0.0456 | |
| 92.36 | 0.663 | 0.0034 | 0.2164 | 0.093 | 0.0869 | |
| 94.04 | 0.561 | 0.0066 | 0.1870 | 0.151 | 0.1273 | |
| 95.30 | 0.482 | 0.0110 | 0.1239 | 0.206 | 0.1482 | 0.0001 |
| 96.14 | 0.429 | 0.0172 | 0.0658 | 0.250 | 0.1422 | 0.0001 |
| 96.56 | 0.403 | 0.0270 | 0.0295 | 0.273 | 0.1168 | 0.0004 |
| 96.98 | 0.378 | 0.0406 | 0.0124 | 0.297 | 0.0925 | 0.0013 |
| 97.40 | 0.353 | 0.0586 | 0.0049 | 0.322 | 0.0705 | 0.0038 |
| 97.82 | 0.328 | 0.0809 | 0.0018 | 0.349 | 0.0516 | 0.0106 |
| 98.24 | 0.304 | 0.1082 | 0.0006 | 0.376 | 0.0362 | 0.0269 |
| 98.66 | 0.282 | 0.1392 | 0.0002 | 0.403 | 0.0242 | 0.0640 |
| 99.50 | 0.234 | 0.1548 | 0.0001 | 0.459 | 0.0165 | 0.1261 |
| 100.76 | 0.181 | 0.1437 | | 0.545 | 0.0106 | 0.1948 |
| 102.44 | 0.119 | 0.1075 | | 0.655 | 0.0058 | 0.2255 |
| 104.54 | 0.065 | 0.0630 | | 0.776 | 0.0024 | 0.1889 |
| 107.06 | 0.028 | 0.0278 | | 0.883 | 0.0006 | 0.1120 |
| 110.00 | 0.009 | 0.0088 | | 0.954 | 0.0001 | 0.0456 |
| Σ | | 1.0001 | 1.0000 | | 1.0000 | 1.0001 |
| R | | 0.0000 | 0.0000 | | 0.0000 | 0.0000 |

TABLE XXII

*Series II*

| Comparison Stimulus | q | Q | Q¹ | p | P | P¹ |
|---|---|---|---|---|---|---|
| 84.80 | 0.948 | | 0.0518 | 0.005 | 0.0052 | |
| 85.64 | 0.932 | | 0.0641 | 0.008 | 0.0077 | |
| 86.48 | 0.913 | | 0.0767 | 0.013 | 0.0131 | |
| 87.32 | 0.890 | | 0.0886 | 0.016 | 0.0160 | |
| 88.16 | 0.863 | | 0.0986 | 0.023 | 0.0222 | |
| 89.00 | 0.831 | | 0.1047 | 0.032 | 0.0301 | |
| 89.84 | 0.796 | 0.0001 | 0.1054 | 0.044 | 0.0398 | |
| 90.68 | 0.755 | 0.0002 | 0.1003 | 0.059 | 0.0513 | |
| 91.52 | 0.712 | 0.0007 | 0.0893 | 0.078 | 0.0635 | |
| 92.36 | 0.664 | 0.0020 | 0.0740 | 0.101 | 0.0761 | |
| 93.20 | 0.614 | 0.0048 | 0.0565 | 0.129 | 0.0871 | |
| 94.04 | 0.562 | 0.0101 | 0.0394 | 0.161 | 0.0949 | |
| 94.88 | 0.509 | 0.0187 | 0.0248 | 0.199 | 0.0982 | 0.0001 |
| 95.72 | 0.456 | 0.0308 | 0.0140 | 0.242 | 0.0953 | 0.0004 |
| 96.56 | 0.403 | 0.0456 | 0.0070 | 0.288 | 0.0863 | 0.0014 |
| 97.40 | 0.352 | 0.0615 | 0.0031 | 0.339 | 0.0723 | 0.0039 |
| 98.24 | 0.304 | 0.0764 | 0.0012 | 0.394 | 0.0554 | 0.0090 |
| 99.08 | 0.259 | 0.0877 | 0.0004 | 0.449 | 0.0384 | 0.0182 |
| 99.92 | 0.218 | 0.0944 | 0.0001 | 0.506 | 0.0238 | 0.0322 |
| 100.76 | 0.180 | 0.0953 | | 0.563 | 0.0131 | 0.0507 |
| 101.60 | 0.147 | 0.0914 | | 0.618 | 0.0063 | 0.0716 |
| 102.44 | 0.119 | 0.0836 | | 0.672 | 0.0026 | 0.0915 |
| 103.28 | 0.094 | 0.0732 | | 0.722 | 0.0009 | 0.1076 |
| 104.12 | 0.074 | 0.0619 | | 0.768 | 0.0003 | 0.1167 |
| 104.96 | 0.057 | 0.0505 | | 0.809 | 0.0001 | 0.1186 |
| 105.80 | 0.043 | 0.0399 | | 0.846 | | 0.1132 |
| 106.64 | 0.032 | 0.0309 | | 0.878 | | 0.1026 |
| 107.48 | 0.024 | 0.0232 | | 0.904 | | 0.0886 |
| 108.32 | 0.017 | 0.0170 | | 0.926 | | 0.0736 |
| Σ | | 0.9999 | 1.0000 | | 1.0000 | 0.9999 |
| R | | 0.0000 | 0.0000 | | 0.0000 | 0.0000 |

TABLE XXIII

*Series III*

| Comparison Stimulus | q | Q | $Q^1$ | p | P | $P^1$ |
|---|---|---|---|---|---|---|
| 84.80 | 0.941 | | 0.0592 | 0.005 | 0.0046 | |
| 86.06 | 0.913 | | 0.0819 | 0.008 | 0.0084 | |
| 87.32 | 0.876 | 0.0001 | 0.1062 | 0.015 | 0.0148 | |
| 88.58 | 0.830 | 0.0007 | 0.1279 | 0.026 | 0.0249 | |
| 89.84 | 0.774 | 0.0030 | 0.1412 | 0.042 | 0.0396 | |
| 91.10 | 0.709 | 0.0095 | 0.1408 | 0.065 | 0.0594 | |
| 92.36 | 0.636 | 0.0233 | 0.1248 | 0.099 | 0.0836 | 0.0001 |
| 93.62 | 0.557 | 0.0461 | 0.0965 | 0.142 | 0.1088 | 0.0006 |
| 94.88 | 0.477 | 0.0754 | 0.0636 | 0.197 | 0.1294 | 0.0029 |
| 96.14 | 0.397 | 0.1043 | 0.0349 | 0.264 | 0.1388 | 0.0100 |
| 97.40 | 0.322 | 0.1245 | 0.0156 | 0.340 | 0.1318 | 0.0263 |
| 98.66 | 0.253 | 0.1312 | 0.0055 | 0.423 | 0.1083 | 0.0543 |
| 99.92 | 0.193 | 0.1239 | 0.0015 | 0.510 | 0.0753 | 0.0904 |
| 101.18 | 0.142 | 0.1067 | 0.0003 | 0.596 | 0.0431 | 0.1251 |
| 102.44 | 0.102 | 0.0848 | 0.0001 | 0.678 | 0.0198 | 0.1470 |
| 103.70 | 0.070 | 0.0630 | | 0.752 | 0.0071 | 0.1505 |
| 104.96 | 0.047 | 0.0441 | | 0.816 | 0.0019 | 0.1367 |
| 106.22 | 0.030 | 0.0293 | | 0.869 | 0.0004 | 0.1122 |
| 107.48 | 0.019 | 0.0186 | | 0.910 | 0.0001 | 0.0847 |
| 108.74 | 0.011 | 0.0114 | | 0.941 | | 0.0592 |
| $\Sigma$ | | 0.9999 | 1.0000 | | 1.0001 | 1.0000 |
| R | | 0.0000 | 0.0000 | | 0.0000 | 0.0000 |

Table XXIV

*Series IV*

| Comparison Stimulus | q | Q | $Q^1$ | p | P | $P^1$ |
|---|---|---|---|---|---|---|
| 84.80 | 0.954 | | 0.0464 | 0.008 | 0.0076 | |
| 86.48 | 0.919 | 0.0004 | 0.0770 | 0.015 | 0.0151 | |
| 88.16 | 0.868 | 0.0026 | 0.1157 | 0.028 | 0.0278 | |
| 89.84 | 0.798 | 0.0121 | 0.1537 | 0.051 | 0.0480 | |
| 91.52 | 0.710 | 0.0370 | 0.1762 | 0.084 | 0.0761 | 0.0003 |
| 93.20 | 0.606 | 0.0803 | 0.1695 | 0.133 | 0.1096 | 0.0019 |
| 94.88 | 0.495 | 0.1297 | 0.1320 | 0.198 | 0.1415 | 0.0091 |
| 96.56 | 0.384 | 0.1634 | 0.0796 | 0 279 | 0.1603 | 0.0293 |
| 98.24 | 0.282 | 0.1672 | 0.0357 | 0.374 | 0.1547 | 0.0680 |
| 99.92 | 0.195 | 0.1434 | 0.0113 | 0.476 | 0.1235 | 0.1194 |
| 101.60 | 0.137 | 0.1166 | 0.0024 | 0.581 | 0.0788 | 0.1646 |
| 103.28 | 0.077 | 0.0713 | 0.0003 | 0.680 | 0.0387 | 0.1851 |
| 104.96 | 0.044 | 0.0424 | | 0.768 | 0.0140 | 0.1749 |
| 106.64 | 0.023 | 0.0231 | | 0.840 | 0.0036 | 0.1433 |
| 108.32 | 0.011 | 0.0106 | | 0.896 | 0.0006 | 0.1041 |
| $\Sigma$ | | 1.0001 | 0.9999 | | 0.9999 | 1.0000 |
| R | | 0.0000 | 0.0000 | | 0.0001 | 0.0000 |

Table XXV

*Series V*

| Comparison Stimulus | q | Q | $Q^1$ | p | P | $P^1$ |
|---|---|---|---|---|---|---|
| 84.80 | 0.947 | 0.0006 | 0.0526 | 0.006 | 0.0056 | |
| 86.90 | 0.896 | 0.0059 | 0.0986 | 0.015 | 0.0149 | |
| 89.00 | 0.815 | 0.0288 | 0.1570 | 0.036 | 0.0351 | 0.0002 |
| 91.10 | 0.703 | 0.0837 | 0.2055 | 0.076 | 0.0716 | 0.0025 |
| 93.20 | 0.568 | 0.1566 | 0.2101 | 0.143 | 0.1250 | 0.0161 |
| 95.30 | 0.425 | 0.2040 | 0.1587 | 0.242 | 0.1813 | 0.0586 |
| 97.40 | 0.291 | 0.1970 | 0.0833 | 0.370 | 0.2099 | 0.1315 |
| 99.50 | 0.181 | 0.1493 | 0.0280 | 0.514 | 0.1832 | 0.1978 |
| 101.60 | 0.101 | 0.0928 | 0.0056 | 0.656 | 0.1138 | 0.2133 |
| 103.70 | 0.051 | 0.0494 | 0.0006 | 0.779 | 0.0465 | 0.1757 |
| 105.80 | 0.023 | 0.0227 | | 0.852 | 0.0112 | 0.1380 |
| 107.90 | 0.009 | 0.0092 | | 0.934 | 0.0018 | 0.0662 |
| Σ | | 1.0000 | 1.0000 | | 0.9999 | 0.9999 |
| R | | 0.0000 | 0.0000 | | 0.0001 | 0.0000 |

TABLE XXVI

*Series VI*

| Comparison Stimulus | q | Q | $Q^1$ | p | P | $P^1$ |
|---|---|---|---|---|---|---|
| 84.80 | 0.939 | 0.0024 | 0.0610 | 0.004 | 0.0040 | |
| 87.32 | 0.873 | 0.0176 | 0.1193 | 0.019 | 0.0189 | 0.0001 |
| 89.84 | 0.770 | 0.0677 | 0.1885 | 0.039 | 0.0381 | 0.0013 |
| 92.36 | 0.632 | 0.1509 | 0.2323 | 0.093 | 0.0873 | 0.0131 |
| 94.88 | 0.475 | 0.2161 | 0.2094 | 0.189 | 0.1610 | 0.0619 |
| 97.40 | 0.321 | 0.2151 | 0.1287 | 0.329 | 0.2272 | 0.1556 |
| 99.92 | 0.193 | 0.1602 | 0.0490 | 0.499 | 0.2313 | 0.2328 |
| 102.44 | 0.103 | 0.0953 | 0.0105 | 0.669 | 0.1553 | 0.2299 |
| 104.96 | 0.048 | 0.0466 | 0.0012 | 0.810 | 0.0623 | 0.1629 |
| 107.48 | 0.019 | 0.0188 | 0.0001 | 0.906 | 0.0132 | 0.0890 |
| 110.00 | 0.007 | 0.0070 | | 0.960 | 0.0013 | 0.0394 |
| 112.52 | 0.002 | 0.0020 | | 0.986 | 0.0001 | 0.0140 |
| Σ | | 0.9997 | 1.0000 | | 1.0000 | 1.0000 |
| R | | 0.0002 | 0.0000 | | 0.0000 | 0.0000 |

TABLE XXVII

*Series VII*

| Comparison Stimulus | q | Q | $Q^1$ | p | P | $P^1$ |
|---|---|---|---|---|---|---|
| 84.80 | 0.936 | 0.0090 | 0.0635 | 0.006 | 0.0062 | |
| 87.74 | 0.851 | 0.0546 | 0.1395 | 0.024 | 0.0235 | 0.0012 |
| 90.68 | 0.711 | 0.1581 | 0.2301 | 0.070 | 0.0684 | 0.0158 |
| 93.62 | 0.529 | 0.2494 | 0.2672 | 0.168 | 0.1519 | 0.0837 |
| 96.56 | 0.340 | 0.2434 | 0.1977 | 0.328 | 0.2456 | 0.2067 |
| 99.50 | 0.185 | 0.1623 | 0.0831 | 0.529 | 0.2670 | 0.2734 |
| 102.44 | 0.084 | 0.0802 | 0.0173 | 0.721 | 0.1713 | 0.2243 |
| 105.38 | 0.031 | 0.0307 | 0.0015 | 0.865 | 0.0572 | 0.1260 |
| 108.32 | 0.009 | 0.0094 | 0.0001 | 0.947 | 0.0085 | 0.0523 |
| 111.26 | 0.002 | 0.0023 | | 0.983 | 0.0005 | 0.0166 |
| Σ | | 0.9994 | 1.0000 | | 1.0001 | 1.0000 |
| R | | 0.0006 | 0.0000 | | 0.0000 | 0.0000 |

TABLE XXVIII

*Series VIII*

| Comparison Stimulus | q | Q | $Q^1$ | p | P | $P^1$ |
|---|---|---|---|---|---|---|
| 84.80 | 0.952 | 0.0116 | 0.0480 | 0.005 | 0.0048 | 0.0001 |
| 88.16 | 0.865 | 0.0775 | 0.1288 | 0.023 | 0.0227 | 0.0035 |
| 91.52 | 0.704 | 0.2137 | 0.2433 | 0.080 | 0.0779 | 0.0409 |
| 94.88 | 0.491 | 0.2927 | 0.2952 | 0.209 | 0.1872 | 0.1678 |
| 98.24 | 0.279 | 0.2308 | 0.2053 | 0.416 | 0.2943 | 0.2979 |
| 101.60 | 0.126 | 0.1189 | 0.0695 | 0.648 | 0.2678 | 0.2768 |
| 104.96 | 0.043 | 0.0427 | 0.0096 | 0.835 | 0.1214 | 0.1551 |
| 108.32 | 0.012 | 0.0116 | 0.0004 | 0.942 | 0.0225 | 0.0580 |
| $\Sigma$ |  | 0.9995 | 1.0001 |  | 0.9986 | 1.0001 |
| R |  | 0.0006 | 0.0000 |  | 0.0014 | 0.0000 |

TABLE XXIX

*Series IX*

| Comparison Stimulus | q | Q | $Q^1$ | p | P | $P^1$ |
|---|---|---|---|---|---|---|
| 84.80 | 0.968 | 0.0187 | 0.0316 | 0.004 | 0.0044 | 0.0002 |
| 88.58 | 0.876 | 0.1358 | 0.1203 | 0.025 | 0.0249 | 0.0084 |
| 92.36 | 0.673 | 0.3192 | 0.2773 | 0.097 | 0.0940 | 0.0801 |
| 96.14 | 0.397 | 0.3120 | 0.3443 | 0.262 | 0.2295 | 0.2500 |
| 99.92 | 0.167 | 0.1573 | 0.1887 | 0.507 | 0.3280 | 0.3295 |
| 103.70 | 0.047 | 0.0468 | 0.0360 | 0.752 | 0.2400 | 0.2203 |
| 107.48 | 0.009 | 0.0086 | 0.0018 | 0.909 | 0.0720 | 0.0886 |
| 111.26 | 0.001 | 0.0010 |  | 0.977 | 0.0070 | 0.0229 |
| $\Sigma$ |  | 0.9994 | 1.0000 |  | 0.9998 | 1.0000 |
| R |  | 0.0006 | 0.0000 |  | 0.0001 | 0.0000 |

TABLE XXX

*Series X*

| Comparison Stimulus | q | Q | $Q^1$ | p | P | $P^1$ |
|---|---|---|---|---|---|---|
| 84.80 | 0.945 | 0.0544 | 0.0550 | 0.002 | 0.0020 | 0.0006 |
| 89.00 | 0.805 | 0.2375 | 0.1842 | 0.021 | 0.0214 | 0.0287 |
| 93.20 | 0.548 | 0.3583 | 0.3435 | 0.121 | 0.1183 | 0.2130 |
| 97.40 | 0.269 | 0.2402 | 0.3050 | 0.377 | 0.3239 | 0.3999 |
| 101.60 | 0.088 | 0.0860 | 0.1023 | 0.707 | 0.3779 | 0.2662 |
| 105.80 | 0.018 | 0.0182 | 0.0097 | 0.919 | 0.1440 | 0.0796 |
| 110.00 | 0.002 | 0.0024 | 0.0002 | 0.988 | 0.0125 | 0.0120 |
| $\Sigma$ |  | 0.9970 | 0.9999 |  | 1.0000 | 1.0000 |
| R |  | 0.0031 | 0.0000 |  | 0.0001 | 0.0000 |

TABLE XXXI

subject I; one table being given to each of the ten series [I-X]. In the first columns are found the intensities of the comparison stimuli used in each particular series. The second columns give the probabilities of a lighter judgment on these comparison stimuli. The third and fourth columns give, under the headings Q and $Q_1$, the probabilities with which the different comparison stimuli appear as determinations of the just perceptible and of the just imperceptible negative difference. The next column gives the probabilities with which heavier judgments may be expected on the stimuli. These last values serve as a basis for the calculation of the probabilities of the different stimuli for being observed as determinations of the just perceptible and of the just imperceptible positive difference, the values of which are found in the last columns of the table. The numbers at the bottom of each column—marked Σ—give the sums of all of the terms and the numbers R give the values of the remainder. These remainders and the sums of the probabilities when added up come to unity within the limit of 0.0001 and thus prove the correctness of the computation. Tables XXXII-XLI are similarly constructed and give the corresponding values of subject II.

It will be noticed that the size of the remainder is in no case so large as to invalidate the series. There is a tendency for the size of the remainder to increase as the series decreases in length. A glance at the table that follows, which contains all the remainders for both subjects, shows this tendency. In the first four

*Series I (G)*

| Comparison Stimulus | q | Q | $Q^1$ | p | P | $P^1$ |
|---|---|---|---|---|---|---|
| 84.80 | 0.921 | 0.0007 | 0.0786 | 0.010 | 0.0100 | |
| 87.74 | 0.822 | 0.0036 | 0.1642 | 0.031 | 0.0305 | |
| 90.26 | 0.692 | 0.0099 | 0.2331 | 0.074 | 0.0712 | |
| 92.36 | 0.560 | 0.0183 | 0.2308 | 0.136 | 0.1210 | |
| 94.04 | 0.448 | 0.0265 | 0.1618 | 0.207 | 0.1587 | 0.0001 |
| 95.30 | 0.367 | 0.0342 | 0.0833 | 0.272 | 0.1653 | 0.0001 |
| 96.14 | 0.315 | 0.0429 | 0.0330 | 0.320 | 0.1418 | 0.0006 |
| 96.56 | 0.291 | 0.0558 | 0.0108 | 0.346 | 0.1042 | 0.0016 |
| 96.98 | 0.267 | 0.0699 | 0.0032 | 0.371 | 0.0733 | 0.0040 |
| 97.40 | 0.244 | 0.0847 | 0.0009 | 0.398 | 0.0494 | 0.0097 |
| 97.82 | 0.223 | 0.0995 | 0.0002 | 0.425 | 0.0317 | 0.0218 |
| 98.24 | 0.202 | 0.1132 | 0.0001 | 0.453 | 0.0195 | 0.0457 |
| 98.66 | 0.183 | 0.1254 | | 0.481 | 0.0113 | 0.0902 |
| 99.50 | 0.148 | 0.1192 | | 0.532 | 0.0065 | 0.1501 |
| 100.76 | 0.105 | 0.0941 | | 0.619 | 0.0035 | 0.1995 |
| 102.44 | 0.062 | 0.0596 | | 0.720 | 0.0015 | 0.2036 |
| 104.54 | 0.030 | 0.0292 | | 0.824 | 0.0005 | 0.1550 |
| 107.06 | 0.010 | 0.0105 | | 0.912 | 0.0001 | 0.0853 |
| 110.00 | 0.003 | 0.0026 | | 0.967 | | 0.0328 |
| Σ | | 0.9998 | 1.0000 | | 1.0000 | 1.0001 |
| R | | 0.0001 | 0.0000 | | 0.0000 | 0.0000 |

Table XXXII

*Series II*

| Comparison Stimulus | q | Q | $Q^1$ | p | P | $P^1$ |
|---|---|---|---|---|---|---|
| 84.80 | 0.938 | | 0.0621 | 0.013 | 0.0130 | |
| 85.64 | 0.919 | | 0.0763 | 0.018 | 0.0178 | |
| 86.48 | 0.897 | | 0.0890 | 0.025 | 0.0240 | |
| 87.32 | 0.871 | | 0.0998 | 0.033 | 0.0316 | |
| 88.16 | 0.841 | | 0.1072 | 0.045 | 0.0408 | |
| 89.00 | 0.806 | 0.0001 | 0.1098 | 0.058 | 0.0510 | |
| 89.84 | 0.767 | 0.0001 | 0.1061 | 0.076 | 0.0621 | |
| 90.68 | 0.725 | 0.0005 | 0.0963 | 0.096 | 0.0731 | |
| 91.52 | 0.679 | 0.0015 | 0.0814 | 0.121 | 0.0829 | |
| 92.36 | 0.629 | 0.0037 | 0.0638 | 0.149 | 0.0901 | |
| 93.20 | 0.578 | 0.0080 | 0.0457 | 0.182 | 0.0937 | |
| 94.04 | 0.525 | 0.0153 | 0.0297 | 0.219 | 0.0921 | 0.0001 |
| 94.88 | 0.472 | 0.0261 | 0.0173 | 0.260 | 0.0854 | 0.0004 |
| 95.72 | 0.420 | 0.0400 | 0.0090 | 0.305 | 0.0739 | 0.0012 |
| 96.56 | 0.368 | 0.0555 | 0.0041 | 0.353 | 0.0595 | 0.0031 |
| 97.40 | 0.319 | 0.0708 | 0.0016 | 0.403 | 0.0439 | 0.0071 |
| 98.24 | 0.273 | 0.0834 | 0.0006 | 0.455 | 0.0296 | 0.0141 |
| 99.08 | 0.231 | 0.0916 | 0.0002 | 0.508 | 0.0180 | 0.0252 |
| 99.92 | 0.193 | 0.0946 | 0.0001 | 0.559 | 0.0098 | 0.0404 |
| 100.76 | 0.158 | 0.0922 | | 0.612 | 0.0047 | 0.0581 |
| 101.60 | 0.128 | 0.0856 | | 0.661 | 0.0020 | 0.0766 |
| 102.44 | 0.102 | 0.0762 | | 0.708 | 0.0007 | 0.0931 |
| 103.28 | 0.081 | 0.0653 | | 0.752 | 0.0002 | 0.1054 |
| 104.12 | 0.062 | 0.0539 | | 0.796 | 0.0001 | 0.1089 |
| 104.96 | 0.048 | 0.0433 | | 0.828 | | 0.1112 |
| 105.80 | 0.036 | 0.0337 | | 0.859 | | 0.1055 |
| 106.64 | 0.027 | 0.0256 | | 0.887 | | 0.0959 |
| 107.48 | 0.019 | 0.0191 | | 0.910 | | 0.0835 |
| 108.32 | 0.014 | 0.0139 | | 0.930 | | 0.0703 |
| $\Sigma$ | | 1.0000 | 1.0001 | | 1.0000 | 1.0001 |
| R | | 0.0000 | 0.0000 | | 0.0000 | 0.0000 |

Table XXXIII

*Series III*

| Comparison Stimulus | q | Q | $Q^1$ | p | P | $P^1$ |
|---|---|---|---|---|---|---|
| 84.80 | 0.933 | | 0.0673 | 0.016 | 0.0162 | |
| 86.06 | 0.902 | | 0.0910 | 0.026 | 0.0260 | |
| 87.32 | 0.863 | 0.0002 | 0.1155 | 0.041 | 0.0395 | |
| 88.58 | 0.814 | 0.0011 | 0.1351 | 0.062 | 0.0573 | |
| 89.84 | 0.755 | 0.0042 | 0.1446 | 0.091 | 0.0785 | |
| 91.10 | 0.688 | 0.0123 | 0.1394 | 0.129 | 0.1006 | 0.0002 |
| 92.36 | 0.614 | 0.0284 | 0.1187 | 0.176 | 0.1200 | 0.0009 |
| 93.62 | 0.535 | 0.0533 | 0.0876 | 0.233 | 0.1308 | 0.0036 |
| 94.88 | 0.454 | 0.0829 | 0.0550 | 0.298 | 0.1286 | 0.0109 |
| 96.14 | 0.376 | 0.1100 | 0.0286 | 0.372 | 0.1125 | 0.0262 |
| 97.40 | 0.303 | 0.1270 | 0.0120 | 0.450 | 0.0855 | 0.0509 |
| 98.66 | 0.236 | 0.1297 | 0.0040 | 0.530 | 0.0554 | 0.0820 |
| 99.92 | 0.179 | 0.1198 | 0.0010 | 0.609 | 0.0299 | 0.1120 |
| 101.18 | 0.131 | 0.1012 | 0.0002 | 0.684 | 0.0131 | 0.1326 |
| 102.44 | 0.093 | 0.0790 | | 0.751 | 0.0046 | 0.1387 |
| 103.70 | 0.064 | 0.0579 | | 0.811 | 0.0012 | 0.1302 |
| 104.96 | 0.042 | 0.0402 | | 0.860 | 0.0002 | 0.1117 |
| 106.22 | 0.027 | 0.0263 | | 0.900 | 0.0001 | 0.0887 |
| 107.48 | 0.018 | 0.0165 | | 0.931 | | 0.0656 |
| 108.74 | 0.010 | 0.0099 | | 0.954 | | 0.0459 |
| $\Sigma$ | | 0.9999 | 1.0000 | | 1.0000 | 1.0001 |
| R | | 0.0000 | 0.0000 | | 0.0000 | 0.0000 |

Table XXXIV

*Series IV*

| Comparison Stimulus | q | Q | $Q^1$ | p | P | $P^1$ |
|---|---|---|---|---|---|---|
| 84.80 | 0.922 | 0.0002 | 0.0780 | 0.018 | 0.0183 | |
| 86.48 | 0.874 | 0.0014 | 0.1149 | 0.034 | 0.0330 | |
| 88.16 | 0.812 | 0.0069 | 0.1514 | 0.058 | 0.0552 | |
| 89.84 | 0.733 | 0.0232 | 0.1753 | 0.095 | 0.0849 | 0.0004 |
| 91.52 | 0.639 | 0.0560 | 0.1736 | 0.147 | 0.1186 | 0.0025 |
| 93.20 | 0.536 | 0.1011 | 0.1425 | 0.215 | 0.1481 | 0.0106 |
| 94.88 | 0.430 | 0.1423 | 0.0937 | 0.297 | 0.1612 | 0.0318 |
| 96.56 | 0.329 | 0.1623 | 0.0474 | 0.393 | 0.1496 | 0.0698 |
| 98.24 | 0.239 | 0.1552 | 0.0177 | 0.496 | 0.1145 | 0.1171 |
| 99.92 | 0.165 | 0.1282 | 0.0046 | 0.598 | 0.0697 | 0.1561 |
| 101.60 | 0.107 | 0.0935 | 0.0008 | 0.694 | 0.0326 | 0.1710 |
| 103.28 | 0.066 | 0.0615 | 0.0001 | 0.779 | 0.0112 | 0.1588 |
| 104.96 | 0.038 | 0.0370 | | 0.848 | 0.0027 | 0.1290 |
| 106.64 | 0.021 | 0.0206 | | 0.902 | 0.0004 | 0.0920 |
| 108.32 | 0.011 | 0.0106 | | 0.939 | 0.0001 | 0.0609 |
| Σ | | 1.0000 | 1.0000 | | 1.0001 | 1.0000 |
| R | | 0.0000 | 0.0000 | | 0.0000 | 0.0000 |

Table XXXV

*Series V*

| Comparison Stimulus | q | Q | $Q^1$ | p | P | $P^1$ |
|---|---|---|---|---|---|---|
| 84.80 | 0.906 | 0.0022 | 0.0944 | 0.009 | 0.0091 | |
| 86.90 | 0.838 | 0.0125 | 0.1465 | 0.022 | 0.0220 | |
| 89.00 | 0.746 | 0.0437 | 0.1932 | 0.049 | 0.0472 | 0.0004 |
| 91.10 | 0.631 | 0.1001 | 0.2090 | 0.96 | 0.0887 | 0.0041 |
| 93.20 | 0.503 | 0.1605 | 0.1775 | 0.171 | 0.1421 | 0.0219 |
| 95.30 | 0.375 | 0.1912 | 0.1122 | 0.274 | 0.1895 | 0.0697 |
| 97.40 | 0.259 | 0.1784 | 0.0498 | 0.403 | 0.2020 | 0.1424 |
| 99.50 | 0.165 | 0.1364 | 0.0145 | 0.542 | 0.1624 | 0.2013 |
| 101.60 | 0.097 | 0.0884 | 0.0026 | 0.677 | 0.0928 | 0.2102 |
| 103.70 | 0.052 | 0.0501 | 0.0003 | 0.792 | 0.0351 | 0.1711 |
| 105.80 | 0.025 | 0.0251 | | 0.878 | 0.0080 | 0.1143 |
| 107.90 | 0.011 | 0.0113 | | 0.935 | 0.0011 | 0.0646 |
| Σ | | 0.9999 | 1.0000 | | 1.0000 | 1.0000 |
| R | | 0.0002 | 0.0000 | | 0.0001 | 0.0000 |

Table XXXVI

*Series VI*

| Comparison Stimulus | q | Q | $Q^1$ | p | P | $P^1$ |
|---|---|---|---|---|---|---|
| 84.80 | 0.890 | 0.0069 | 0.1101 | 0.025 | 0.0250 | |
| 87.32 | 0.806 | 0.0321 | 0.1725 | 0.055 | 0.0540 | 0.0008 |
| 89.84 | 0.692 | 0.0895 | 0.2208 | 0.109 | 0.1004 | 0.0069 |
| 92.36 | 0.556 | 0.1621 | 0.2204 | 0.193 | 0.1580 | 0.0326 |
| 94.88 | 0.413 | 0.2047 | 0.1622 | 0.307 | 0.2033 | 0.0914 |
| 97.40 | 0.280 | 0.1929 | 0.0821 | 0.444 | 0.2038 | 0.1652 |
| 99.92 | 0.173 | 0.1440 | 0.0264 | 0.588 | 0.1502 | 0.2083 |
| 102.44 | 0.096 | 0.0884 | 0.0050 | 0.721 | 0.0759 | 0.1956 |
| 104.96 | 0.048 | 0.0462 | 0.0005 | 0.829 | 0.0244 | 0.1446 |
| 107.48 | 0.021 | 0.0211 | | 0.906 | 0.0046 | 0.0881 |
| 110.00 | 0.008 | 0.0084 | | 0.953 | 0.0004 | 0.0458 |
| 112.52 | 0.003 | 0.0030 | | 0.979 | | 0.0206 |
| Σ | | 0.9993 | 1.0000 | | 1.0000 | 0.9999 |
| R | | 0.0008 | 0.0000 | | 0.0000 | 0.0000 |

Table XXXVII

*Series VII*

| Comparison Stimulus | q | Q | $Q^1$ | p | P | $P^1$ |
|---|---|---|---|---|---|---|
| 84.80 | 0.954 | 0.0085 | 0.0459 | 0.009 | 0.0086 | |
| 87.74 | 0.873 | 0.0615 | 0.1208 | 0.029 | 0.0292 | 0.0014 |
| 90.68 | 0.726 | 0.1861 | 0.2287 | 0.082 | 0.0785 | 0.0159 |
| 93.62 | 0.523 | 0.2807 | 0.2886 | 0.164 | 0.1451 | 0.0879 |
| 96.56 | 0.313 | 0.2451 | 0.2170 | 0.343 | 0.2534 | 0.2015 |
| 99.50 | 0.151 | 0.1395 | 0.0840 | 0.536 | 0.2601 | 0.2656 |
| 102.44 | 0.058 | 0.0566 | 0.0141 | 0.720 | 0.1622 | 0.2221 |
| 105.38 | 0.017 | 0.0171 | 0.0009 | 0.860 | 0.0541 | 0.1297 |
| 108.32 | 0.004 | 0.0039 | | 0.942 | 0.0083 | 0.0567 |
| 111.26 | 0.001 | 0.0007 | | 0.981 | 0.0005 | 0.0192 |
| Σ | | 0.9997 | 1.0000 | | 1.0000 | 1.0000 |
| R | | 0.0004 | 0.0000 | | 0.0000 | 0.0000 |

TABLE XXXVIII

*Series VIII*

| Comparison Stimulus | q | Q | $Q^1$ | p | P | $P^1$ |
|---|---|---|---|---|---|---|
| 84.80 | 0.938 | 0.0166 | 0.0621 | 0.011 | 0.0114 | 0.0003 |
| 88.16 | 0.839 | 0.0923 | 0.1508 | 0.041 | 0.0406 | 0.0065 |
| 91.52 | 0.672 | 0.2252 | 0.2582 | 0.115 | 0.1092 | 0.0517 |
| 94.88 | 0.460 | 0.2855 | 0.2856 | 0.254 | 0.2130 | 0.1716 |
| 98.24 | 0.259 | 0.2169 | 0.1803 | 0.450 | 0.2819 | 0.2806 |
| 101.60 | 0.117 | 0.1105 | 0.0557 | 0.661 | 0.2272 | 0.2623 |
| 104.96 | 0.041 | 0.0406 | 0.0070 | 0.829 | 0.0968 | 0.1590 |
| 108.32 | 0.011 | 0.0112 | 0.0003 | 0.932 | 0.0185 | 0.0680 |
| Σ | | 0.9988 | 1.0000 | | 0.9986 | 1.0000 |
| R | | 0.0011 | 0.0000 | | 0.0014 | 0.0000 |

TABLE XXXIX

*Series IX*

| Comparison Stimulus | q | Q | $Q^1$ | p | P | $P^1$ |
|---|---|---|---|---|---|---|
| 84.80 | 0.952 | 0.0287 | 0.0478 | 0.004 | 0.0040 | 0.0006 |
| 88.58 | 0.840 | 0.1586 | 0.1521 | 0.028 | 0.0281 | 0.0200 |
| 92.36 | 0.628 | 0.3179 | 0.2980 | 0.121 | 0.1175 | 0.1488 |
| 96.14 | 0.365 | 0.2912 | 0.3188 | 0.334 | 0.2837 | 0.3383 |
| 99.92 | 0.155 | 0.1463 | 0.1549 | 0.622 | 0.3523 | 0.3091 |
| 103.70 | 0.046 | 0.0454 | 0.0271 | 0.853 | 0.1829 | 0.1408 |
| 107.48 | 0.009 | 0.0092 | 0.0013 | 0.963 | 0.0304 | 0.0367 |
| 111.26 | 0.001 | 0.0012 | | 0.994 | 0.0011 | 0.0058 |
| Σ | | 0.9985 | 1.0000 | | 1.0000 | 1.0001 |
| R | | 0.0014 | 0.0000 | | 0.0001 | 0.0000 |

TABLE XL

*Series X*

| Comparison Stimulus | q | Q | $Q^1$ | p | P | $P^1$ |
|---|---|---|---|---|---|---|
| 84.80 | 0.952 | 0.0390 | 0.0483 | 0.014 | 0.0140 | 0.0023 |
| 89.00 | 0.828 | 0.1978 | 0.1634 | 0.061 | 0.0598 | 0.0366 |
| 93.20 | 0.592 | 0.3468 | 0.3215 | 0.183 | 0.1699 | 0.1733 |
| 97.40 | 0.315 | 0.2697 | 0.3196 | 0.400 | 0.3022 | 0.3188 |
| 101.60 | 0.116 | 0.1123 | 0.1301 | 0.653 | 0.2967 | 0.2817 |
| 105.80 | 0.028 | 0.0280 | 0.0166 | 0.851 | 0.1340 | 0.1418 |
| 110.00 | 0.004 | 0.0044 | 0.0005 | 0.954 | 0.0224 | 0.0455 |
| Σ | | 0.9980 | 1.0000 | | 0.9990 | 1.0000 |
| R | | 0.0020 | 0.0000 | | 0.0010 | 0.0000 |

Table XLI

series there are only two remainders and these are only 0.0001. In the later and shorter series the remainders are very much larger and occur much more frequently. It will also be noticed that there are no remainders for either subject for the just imperceptible differences both positive and negative. This of course indicates that our series were in every case extended enough so that these imperceptible differences would always fall upon one of the stimuli of our series, within the limit of 0.0001. It would also seem that the remainders for the just perceptible negative difference are on the whole greater than those of the just perceptible positive difference.

| | Subject I | | Subject II | |
|---|---|---|---|---|
| Series | Just perceptible negative difference | Just perceptible positive difference | Just perceptible negative difference | Just perceptible positive difference |
| I....... | 0.0000 | 0.0000 | 0.0001 | 0.0000 |
| IV....... | 0.0000 | 0.0001 | 0.0000 | 0.0000 |
| V....... | 0.0000 | 0.0001 | 0.0002 | 0.0001 |
| VI....... | 0.0002 | 0.0000 | 0.0008 | 0.0000 |
| VII....... | 0.0006 | 0.0000 | 0.0004 | 0.0000 |
| VIII....... | 0.0006 | 0.0014 | 0.0011 | 0.0014 |
| IX....... | 0.0006 | 0.0001 | 0.0014 | 0.0001 |
| X....... | 0.0031 | 0.0001 | 0.0020 | 0.0010 |

When we have once obtained the probabilities for the different comparison stimuli with which these four differences may occur, we may derive the most probable value of each of the just perceptible and just imperceptible differences very easily. Multiplying each value of the comparison stimulus by its probability and adding these products we obtain $[xQ]$, $[xQ_1]$, $[xP]$, and $[xP_1]$. These are respectively the most probable values of the just perceptible negative difference, the just imperceptible negative difference, the just perceptible positive difference and the just imperceptible positive difference, calculated on the basis of our experiments by the method of constant stimuli. Tables XLII and XLIII give these values of the four differences for subjects I and II. Opposite the numbers for the series, which are found in the first columns, we have in the 3d, 5th, 7th, and 9th columns the calculated values for these differences.

The observed values of these fundamental differences are found in the other columns of these tables. The observed and calculated values for each series and for every difference, are found directly next to one another so that they may be more easily compared. These observed values are calculated very readily and in the manner explained in our description of the experiment, given above. The values for the just perceptible and imperceptible negative and positive differences are ascertained for each group in every series, by picking out each value according to the definitions of these quantities. There were ten groups in each series, five ascending and five descending, so that we will obtain in each case, ten values for each difference. These ten values are averaged and the result is given as the value of the difference. The ease with which the differences are calculated after we have our experimental data is one of the great advantages of the method of just perceptible differences over the other methods of psychophysical measurement. In this method, the measure of sensitivity is obtained by the simple solving of four averages, which can be performed in a very short space of time. With the method of constant stimuli, on the other hand, a long and complicated series of calculations must be entered into before these same values are obtained.

We now calculate the measure of accuracy that is shown by our observed results of the method of just perceptible differences by means of the probable error. If our threshold is found to be 95 grams and the probable error ± 0.50 grams, it indicates that this threshold will fall within the interval of 94.50 grams and 95.50 grams with the probability of 0.50. This measure of precision is

*Subject I*

| Series | Just perceptible negative difference | | Just imperceptible negative difference | | Just perceptible positive difference | | Just imperceptible positive difference | |
|---|---|---|---|---|---|---|---|---|
| | Observed | Calculated | Observed | Calculated | Observed | Calculated | Observed | Calculated |
| I......... | 99.29 | 99.74 | 94.33 | 92.18 | 96.31 | 95.56 | 100.84 | 102.58 |
| II......... | 99.92 | 101.02 | 90.60 | 89.65 | 95.38 | 94.18 | 103.78 | 104.35 |
| III......... | 97.27 | 99.31 | 90.47 | 90.38 | 94.63 | 95.52 | 101.94 | 103.38 |
| IV......... | 101.10 | 98.32 | 93.70 | 91.66 | 98.41 | 96.27 | 104.12 | 99.76 |
| V......... | 95.51 | 96.78 | 91.73 | 91.96 | 96.14 | 96.79 | 99.71 | 101.46 |
| VI......... | 93.62 | 96.69 | 92.41 | 92.49 | 96.90 | 98.01 | 101.18 | 101.75 |
| VII......... | 97.15 | 95.68 | 96.27 | 92.80 | 102.44 | 97.84 | 102.73 | 100.30 |
| VIII......... | 95.55 | 95.70 | 94.21 | 93.97 | 100.93 | 98.73 | 99.58 | 99.92 |
| IX......... | 96.14 | 95.15 | 96.14 | 94.83 | 101.81 | 99.52 | 101.81 | 100.03 |
| X......... | 93.62 | 93.98 | 96.14 | 94.22 | 102.44 | 99.66 | 99.92 | 98.20 |

Table XLII

*Subject II*

| Series | Just perceptible negative difference | | Just imperceptible negative difference | | Just perceptible positive difference | | Just imperceptible positive difference | |
|---|---|---|---|---|---|---|---|---|
| | Observed | Calculated | Observed | Calculated | Observed | Calculated | Observed | Calculated |
| I......... | 97.82 | 98.41 | 93.66 | 91.23 | 94.96 | 94.77 | 99.54 | 101.91 |
| II......... | 99.08 | 100.56 | 89.76 | 89.23 | 94.46 | 91.76 | 103.03 | 104.11 |
| III......... | 98.66 | 99.01 | 90.60 | 90.10 | 93.75 | 93.43 | 102.31 | 102.53 |
| IV......... | 98.07 | 97.70 | 91.69 | 90.57 | 96.06 | 94.30 | 100.42 | 101.84 |
| V......... | 96.35 | 96.47 | 91.73 | 90.80 | 95.09 | 96.14 | 99.92 | 101.15 |
| VI......... | 97.65 | 96.50 | 94.12 | 91.18 | 99.42 | 93.56 | 100.68 | 101.32 |
| VII......... | 95.09 | 94.95 | 95.97 | 93.10 | 98.32 | 97.61 | 101.26 | 100.38 |
| VIII......... | 95.55 | 95.37 | 96.22 | 93.43 | 99.92 | 97.83 | 100.26 | 99.88 |
| IX......... | 93.49 | 94.43 | 93.12 | 94.13 | 100.30 | 98.21 | 99.54 | 98.16 |
| X......... | 96.14 | 94.38 | 96.98 | 94.76 | 99.50 | 98.66 | 98.24 | 99.28 |

Table XLIII

calculated only for the thresholds and is obtained by the formula

$$\text{P. E.} — 0.6745 \sqrt{\frac{\Sigma v^2}{n\,(n\text{-}1)}}.$$

In this equation $\Sigma v^2$ is the sum of the variations of the different thresholds from the average, and n is the number of thresholds considered. Table XLIV gives the probable errors for both subjects for the two thresholds of increase and decrease. It will be noticed that these values are comparatively constant. Considering the size of the values, the precision of which they are measuring, these quantities are small. In no case is the probable error greater than one per cent of the threshold and very often it is close to one-half a per cent or even less. Thus we conclude that the thresholds in the method of just perceptible differences fall with a high probability within a comparatively limited space.

| Series | Subject I | | Subject II | |
|---|---|---|---|---|
| | Threshold in direction of decrease | Threshold in direction of increase | Threshold in direction of decrease | Threshold in direction of increase |
| I | ±0.50 | ±0.43 | ±0.43 | ±0.44 |
| II | ±0.88 | ±0.82 | ±0.87 | ±0.75 |
| III | ±0.78 | ±0.83 | ±0.79 | ±0.83 |
| IV | ±0.96 | ±0.72 | ±0.83 | ±0.61 |
| V | ±0.72 | ±0.66 | ±0.65 | ±0.65 |
| VI | ±0.27 | ±0.64 | ±0.62 | ±0.52 |
| VII | ±0.53 | ±0.65 | ±0.50 | ±0.63 |
| VIII | ±0.52 | ±0.56 | ±0.57 | ±0.56 |
| IX | ±0.56 | ±0.60 | ±0.62 | ±0.76 |
| X | ±0.55 | ±0.54 | ±0.60 | ±0.72 |

TABLE XLIV

The sums of the products $xP$, $xP^1$, $xQ$ and $xQ^1$ give the most probable values of the just perceptible and just imperceptible positive and negative differences, but a finite number of observations can not be expected to give exactly these results. The outcome of a series depends on chance influences, which prevent us from obtaining the calculated result exactly, and we must be satisfied with determining the limit inside of which we may expect the results to fall with a given probability. The solution of this problem is given by the theorem of Tchebicheff, which applies to problems of this kind (cfr. Urban, *Statistical Methods,* pp. 65, and *Archiv f. d. ges. Psychologie,* Vol. 15, pp. 302-304). We give the formulae for the just perceptible and the just imperceptible positive difference only, because their form for the two other differences is perfectly obvious. Suppose we make n determinations of each one of these quantities with a certain series of comparison stimuli. We then may expect with a probability exceeding $1 - \frac{t^2}{n}$ that the arithmetical mean of all the observations of the just perceptible difference will be within the limits

$$\Sigma x P \pm \frac{1}{t} \sqrt{\Sigma x^2 P - (\Sigma x P)^2}$$

and that of the just imperceptible positive difference between the limits

$$\Sigma x P^1 \pm \frac{1}{t} \sqrt{\Sigma x^2 P^1 - (\Sigma x P^1)^2} \; .$$

Applying the same theorem to the determination of the upper limit of the interval of uncertainty we find that there exists a probability exceeding $1 - \frac{t^2}{n}$ that the actually observed result will be found between the limits

$$\Sigma x \frac{P+P^1}{2} \pm \frac{1}{t} \sqrt{\Sigma x^2 \frac{P+P^1}{2} - \frac{1}{2} (\Sigma x P)^2 - \frac{1}{2} (\Sigma x P^1)^2} \; .^*$$

The difference $\Sigma x^2 P - (\Sigma x P)^2$ plays a part similar in the theorem of Tchebicheff to that of the product 2spq in the theorem of Bernoulli, since the square roots of both these terms determine the size of the interval inside of which the result may be expected with a given probability. The actual determination of these intervals requires the square root of these differences, but this problem is of less interest than the question as to the comparative size of these intervals in series of different length. For this purpose it is sufficient to give these differences as it is done in Table XLV for Subject I and in Table XLVI for Subject II. These tables also contain the values of the sums of the terms xxP which is needed for the calculation of the differences in question. These quantities also enable us to determine the limits for the result of a series of determinations of the upper

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* The theorem of Tchebicheff enables us merely to determine the limits inside of which we may expect the result of an actual observation to fall with a given probability. Wirth [*Zur erkenntnisstheoretischen und mathematischen Begründung der Massmethoden für die Unterschiedsschwelle, Archiv f. d. ges. Psychologie,* 1911, Vol. 20, p. 84] seems to believe that this theorem might enable us to find relations between different values of the psychometric functions, but there is no possibility of doing so.

| Series | $\Sigma xxQ$ | $d_1$ | $\Sigma xxQ_1$ | $d_2$ | $\Sigma xxP$ | $d_3$ | $\Sigma xxP_1$ | $d_4$ |
|---|---|---|---|---|---|---|---|---|
| I....... | 9956.04 | 7.99 | 8505.99 | 8.84 | 9138.58 | 6.87 | 10530.34 | 9.74 |
| II....... | 10219.03 | 13.99 | 8044.26 | 7.14 | 8880.87 | 10.97 | 10895.99 | 7.07 |
| III....... | 9875.88 | 13.40 | 8179.67 | 11.13 | 9138.83 | 14.76 | 10697.37 | 9.95 |
| IV....... | 9683.12 | 14.29 | 8388.13 | 12.24 | 9283.47 | 15.86 | 10673.71 | 11.08 |
| V....... | 9381.94 | 15.58 | 8469.76 | 13.12 | 9383.45 | 12.74 | 10306.87 | 12.74 |
| VI....... | 9368.32 | 19.37 | 8571.18 | 16.78 | 9624.59 | 18.63 | 10361.20 | 19.21 |
| VII....... | 9168.66 | 18.80 | 8629.89 | 18.05 | 9591.46 | 16.84 | 9961.88 | 18.79 |
| VIII....... | 9172.02 | 13.53 | 8850.82 | 20.46 | 9754.65 | 7.04 | 10002.67 | 18.66 |
| IX....... | 9069.85 | 16.32 | 9010.68 | 17.95 | 9924.26 | 20.03 | 10027.36 | 21.36 |
| X....... | 8854.31 | 22.07 | 8898.74 | 21.33 | 9949.78 | 17.66 | 9646.89 | 3.65 |

Table XLV

| Series | $\Sigma xxQ$ | $d_1$ | $\Sigma xxQ_1$ | $d_2$ | $\Sigma xxP$ | $d_3$ | $\Sigma xxP_1$ | $d_4$ |
|---|---|---|---|---|---|---|---|---|
| I....... | 9689.23 | 4.70 | 8331.91 |  | 8987.28 | 5.93 | 10396.16 | 10.51 |
| II....... | 10124.14 | 11.83 | 7969.86 | 9.00 | 8424.96 | 5.06 | 10847.20 | 8.31 |
| III....... | 9816.76 | 13.78 | 8127.18 | 7.86 | 8743.51 | 14.34 | 10525.39 | 12.98 |
| IV....... | 9559.64 | 16.30 | 8214.14 | 11.22 | 8910.34 | 17.85 | 10383.03 | 11.64 |
| V....... | 9324.30 | 17.84 | 8257.00 | 12.36 | 9258.82 | 14.97 | 10245.52 | 14.20 |
| VI....... | 9330.03 | 17.78 | 8329.84 | 16.04 | 8774.20 | 20.72 | 10287.80 | 20.01 |
| VII....... | 9029.72 | 14.22 | 8672.56 | 13.33 | 9548.02 | 20.31 | 10094.21 | 18.06 |
| VIII....... | 9105.68 | 10.24 | 8748.01 | 18.85 | 9579.07 | 8.36 | 9996.06 | 19.04 |
| IX....... | 8924.32 | 7.29 | 8878.78 | 18.32 | 9656.84 | 11.64 | 9653.37 | 17.99 |
| X....... | 8924.08 | 16.49 | 9001.06 | 21.60 | 9750.96 | 17.16 | 9881.80 | 25.26 |

Table XLVI

limit of the interval of uncertainty. In our experiments we have in all the cases n = 5, so that the radicals for the limits of the interval of uncertainty can be found by averaging the corresponding values in the tables.

Table XLVII gives these values for both subjects. The greater the value, the greater will be the interval within which we may expect our determination of the threshold to fall with a given probability and therefore the less accurate that determination will be. These quantities definitely tend to increase in size as the series become shorter, and therefore, the determinations of our thresholds by short series of experiments are not so accurate as those obtained by more extended series. Furthermore, it would definitely appear that the determinations of our thresholds by the graded series I are more accurate than any of the others.

| Series | Subject I | | Subject II | |
|---|---|---|---|---|
| | $d^1$ | $d^{11}$ | $d^1$ | $d^{11}$ |
| I....... | 8.42 | 8.30 | 6.85 | 8.22 |
| II....... | 10.56 | 9.02 | 9.84 | 6.68 |
| III....... | 12.26 | 12.36 | 11.48 | 13.66 |
| IV....... | 13,26 | 13.47 | 13.76 | 14.74 |
| V....... | 14.30 | 12.74 | 15.10 | 14.58 |
| VI....... | 18.08 | 18.92 | 16.91 | 20.36 |
| VII....... | 18.42 | 17.82 | 13.78 | 19.18 |
| VIII....... | 17.00 | 12.85 | 14.54 | 13.70 |
| IX....... | 17.14 | 20.70 | 12.80 | 14.82 |
| X....... | 21.70 | 10.66 | 19.04 | 21.21 |

TABLE XLVII

We are now in the possession of all the data necessary for the comparison of the two methods under discussion. The thresholds are the important values in these methods, since they are the basis for the determination of the sensitivity of the subject. It is by the means of the values of the thresholds, then, that we will compare the methods of just perceptible differences and of constant stimuli. Tables XLVIII and XLIX show the values of the thresholds for both subjects, obtained in the different ways that have been described above. The first columns in these tables give the numbers of the series into which the results of the method of just perceptible differences were divided. The values of the threshold in the direction of decrease are found in the next three columns. The first of these are the values obtained from the re-

*Subject I*

| Series | Threshold in the direction of decrease | | | Threshold in the direction of increase | | |
|---|---|---|---|---|---|---|
| | Method of constant stimuli | Method of Just Perceptible Differences | | Method of constant stimuli | Method of Just Perceptible Differences | |
| | | Calculated | Observed | | Calculated | Observed |
| I | 95.02 | 95.96 | 96.81 | 100.10 | 99.07 | 98.58 |
| II | 95.02 | 95.33 | 95.26 | 99.82 | 99.26 | 99.58 |
| III | 94.52 | 94.85 | 93.87 | 99.77 | 99.45 | 98.28 |
| IV | 94.81 | 94.99 | 97.40 | 100.30 | 99.76 | 101.26 |
| V | 94.20 | 94.37 | 93.62 | 99.30 | 99.13 | 97.92 |
| VI | 94.48 | 94.59 | 93.02 | 99.93 | 99.88 | 99.04 |
| VII | 94.06 | 94.24 | 96.71 | 99.09 | 99.07 | 102.58 |
| VIII | 94.74 | 94.83 | 94.88 | 99.45 | 99.33 | 100.26 |
| IX | 94.75 | 94.99 | 96.14 | 99.82 | 99.78 | 101.81 |
| X | 93.89 | 94.10 | 94.88 | 98.93 | 98.93 | 101.18 |

TABLE XLVIII

*Subject II*

| Series | Threshold in the direction of decrease | | | Threshold in the direction of increase | | |
|---|---|---|---|---|---|---|
| | Method of constant stimuli | Method of Just Perceptible Differences | | Method of constant stimuli | Method of Just Perceptible Differences | |
| | | Calculated | Observed | | Calculated | Observed |
| I | 93.26 | 94.81 | 95.74 | 98.94 | 98.34 | 97.25 |
| II | 94.44 | 94.89 | 94.42 | 98.96 | 97.94 | 98.74 |
| III | 94.16 | 94.55 | 94.63 | 98.19 | 97.98 | 98.03 |
| IV | 93.76 | 94.13 | 94.88 | 98.32 | 98.07 | 98.24 |
| V | 93.24 | 93.63 | 94.04 | 98.86 | 98.64 | 97.50 |
| VI | 93.34 | 93.84 | 95.88 | 98.37 | 97.44 | 100.05 |
| VII | 93.93 | 94.02 | 95.53 | 98.96 | 98.99 | 99.79 |
| VIII | 94.27 | 94.40 | 95.88 | 99.00 | 98.85 | 100.09 |
| IX | 94.20 | 94.28 | 93.30 | 98.34 | 98.18 | 99.92 |
| X | 94.57 | 94.57 | 96.56 | 99.04 | 98.97 | 98.87 |

TABLE XLIX

sults of the method of constant stimuli, that were taken simultaneously with the different series of the method of just perceptible differences. In the next column are the calculated thresholds of the method of just perceptible differences, and in the third column are the observed values for the same method. The second halves of the tables show the same arrangement of values for the threshold in the direction of increase.

An examination of these tables shows unsystematic variations between the different results that are to be expected. That is, within a given set, some individual results are greater and some are smaller than the average, but these variations occur in a haphazard manner and not in a regular way. The larger the amount of data that goes to determine any value or set of values, the smaller these chance variations should become. This is borne out by our results, as the random variations are greatest in the observed results of the method of just perceptible differences, which values are determined by smaller experimental data than are the others. But these variations are comparatively small and seem to point to a high degree of similarity between the two methods.

There is one observation, however, that may be of significance. If we compare the observed thresholds of the method of constant stimuli and the calculated thresholds of the method of just perceptible differences, we find that the variations, in the case of both subjects, are always in one direction. The calculated thresholds in the direction of decrease by the method of just perceptible differences are constantly larger than the corresponding values in the method of constant stimuli; and for the threshold in the direction of increase, they are constantly smaller. Thus the limits of the interval of uncertainty are constantly narrowed in the just perceptible difference method when compared with the same interval of the other method. This is a serious fault as it is just this interval that is the measure of sensitivity of our subject. If the values of one method had been constantly greater than those of the other method for both thresholds, the interval of uncertainty would have remained the same although the point of subjective equality would have changed. It will be noticed that these systematic variations are greatest in the long series of short steps, while in the short series of large steps they become so small that they can be practically disregarded. The variation is greatest in series I, which was performed in an effort to test out a graded approach of the central values of the series. This may be due to the fact that by a carefully graded approach, we emphasize before hand the probability that the differences will fall on the central values. The greater the number of results that go to make up a value, the more nearly should that value coincide with a calculated probability. If this be true, then the values of the series I to IV should be more nearly correct than the series VIII to X. It is a curious fact that the more nearly the experimental arrangement of the method of just perceptible differences approaches that of the method of constant stimuli, the closer do the values under discussion coincide. The experimental arrangement of the method of constant stimuli consists of a small number of pairs of stimuli with comparative large differences of intensity in the steps of the series. This is like the arrangement of series X, and here the values of the thresholds for the two methods practically agree.

Series II has quite a different arrangement; having many steps of a small interval and here the greatest discrepancies are found between the two methods. Thus there seem to be discrepancies that may be due, either to the length of the series, or to the attitude with which the subject approached the two methods. Our form of experimentation tried to eliminate any difference in attitude and was probably almost entirely, but not absolutely, successful. If we had been able to devise a means by which the attitude of the subject was identical for both methods, it seems very probable that our results would have showed a still closer agreement.

In practically all of the studies by these methods, it has been found that a higher sensitivity was obtained by the method of just perceptible differences than by the method of constant stimuli. If the difference in our values under discussion are significant, we could then account for the discrepancies in the results of the former studies, as a fundamental difference in the methods themselves.

But these differences are not large enough to have us disregard the method of just perceptible differences as a practical method of psychophysical measurement. It seems wisest, however, to disregard the form of a graded approach of the central values, as the method in this form seems to show its greatest discrepancies. It would also seem that a short series of large steps is preferable to a long series of small steps. The best form of experimentation with this method would be to take a considerable number of series, each series to consist of not more than ten steps and with a considerable difference of weight between the steps. If such a series is used, the results of this study seem to indicate, that any discrepancies between the results obtained in this way and those of the method of constant stimuli taken under identical conditions would be so small that they could be disregarded.

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